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Comparative Analysis of Senior vs Junior Ski Jumpers

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Comparative Analysis of Senior vs Junior Ski Jumpers submitted by Gordon Ernest Marchiori in partial fulfilment of the requirements for the degree of Master of Science.

DEDICATION

It is easy in the world
to follow the world's opinions;
it is easy in solitude
to follow our own;
but the great man is he
who in the midst of the crowd
keeps with perfect sweetness
the independence of solitude.

Anonymous

To my parents, who have stood beside me in times of trouble and in times of need, and most important of all, through all the good times.

To my brother Paul, his wife Tammy, and their child Christopher, because you are always with me wherever I go.

ABSTRACT

The purpose of this study was to perform a comparative analysis between two groups of ski jumpers and to ascertain the kinematic factors which influenced the take-off and early flight phases of ski jumping. The two groups of ski jumpers were comprised of senior and junior competitors on the Little Thunder 25 metre ski jumping hill in Thunder Bay, Ontario on January 2, 1982. Two 16mm pin registered Photo Sonics 1PL cameras were used for the acquisition of cinematographic data. A Lafayette pin registered film analyzer, Bendix digitizing board, and a Hewlett Packard 9825B micro computer were utilized for analysis. The results indicated significant differences among the senior and junior ski jumpers. Significant differences were observed in body position and rate of movement. Kinematic factors which differed significantly between the groups included: knee angle, trunk, thigh, and leg angle, the CM pathway, the ski to the horizontal angle, the ski to the trunk angle, and the horizontal distance from the centre of mass to the ankle. Vertical velocity and the angle of attack at take-off were significant ($p<.01$) predictors for distance jumped. The CM pathway, the angle of attack, and the ski to trunk angle early in flight, contributed significantly ($p<.01$) to distance jumped.

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CHAPTER I

Introduction

The sport of ski jumping is an exciting event for both competitors and spectators. The first ski jumping competition took place in Morgedal, near Telemark in 1866 (Litell, 1978). The sport of ski jumping so intrigued sport scientists that research was undertaken to explain the phenomenon of jumping into space. Biomechanical studies of ski jumping date from 1926 when Straumann published the first results of his observations concerning the flight paths of ski jumpers. In 1927, Straumann presented a detailed mechanical analysis on air resistance and flight paths based on modeled wind-tunnel experiments. Since that time, many European, Japanese, and American researchers have contributed to the evolution of the modern ski jumping technique used today.

Ski jumping technique has been divided into four phases: in-run, take-off, flight, and landing. Researchers have been mainly concerned with the take-off and flight phases. For example, Straumann (1927), Tani & Iuchi (1971), Krylov & Remizov (1975), as well as Baumann (1978), have studied the aerodynamics of the flight phase in ski jumping and have arrived at optimum angles for body and ski positioning. Baumann (1978) and Campbell (1979) studied the

take-off phase of ski jumping and emphasized the significance of factors such as take-off angle, take-off velocity, maximum normal velocity and acceleration as well as normal velocity and direction of motion at take-off.

Sport scientists have investigated many specific aspects or factors which influenced performance in ski jumping. Jumpers and their coaches have received valuable information from these researchers concerning the different phases of ski jumping.

Campbell (1979) suggested that the take-off has the most significant effect on the length of air flight. Nasimovich (1973) declared that timing of the take-off has considerable influence on distance travelled. Baumann (1978) declared that the purposes for take-off are to give the centre of mass (CM) a maximum normal velocity, to produce a favourable body position at the jump's edge, and to initialize the suitable angular momentum for the forward rotation of the body immediately after the take-off point.

It is evident upon reviewing the literature that take-off and flight are the most important factors with respect to distance jumped. Tveit & Pedersen (1979) summarized the take-off movement by stating that it is important to focus on the problem of getting from an aerodynamic position before the take-off into an aerodynamic position as early as possible after the take-off with a minimum of air resistance. This statement would suggest an investigation of take-off and early flight to determine the

jumpers movements during these phases.

Hay (1973) expressed his concerns about research efforts in the field of biomechanics. He emphasized that an abundant number of studies were conducted in which the goal was to describe and/or explain the movement techniques employed by above average athletes. The movement techniques of the general population who fall below the level of the physically gifted athlete have received scant attention from biomechanical researchers.

Most of the reported research has been conducted on elite ski jumpers. There has been no study uncovered in the research to date that has endeavoured to determine how young developing jumpers differ from elite jumpers. It is the lack of research on these young jumpers that creates a need for this study. Some questions arise along with this need. What factor or factors are most important in ski jumping? Do these factors influence junior and senior skiers' performances equally?

Statement of the Problem

The purpose of this study was to investigate:

1. the body and ski positions of the jumper during the take-off and early flight phases of ski jumping,
2. selected kinematic factors which influence the take-off and early flight phases of ski jumping, and
3. to perform a comparative analysis between junior and senior groups of ski jumpers with reference to the

take-off and early flight phases.

Limitations

The limitations of this study resulted from data acquisition and analysis techniques.

1. Motion occurs in three planes. The objective of the ski jumper is to travel a maximum distance in a linear fashion. This movement occurred parallel to the film plane of the camera. Movements out of this parallel plane should be minimal and were not measured.
2. Perspective error and human error in the use of film analysis were unavoidable but great care was taken to minimize these errors.
3. The accuracy of establishing body segment parameters was limited to the accuracy of the Humanscale Anatomical Data (Diffrient, 1979) and also the ability of the investigator to accurately locate proximal and distal endpoints of the body segments.
4. The smoothing technique reduced the amount of random error from the raw data obtained from the film.
5. Further limitations to this study were attributed to the weather (heavy snowfall) and the in-run track conditions (due to the snow) during data collection.

Delimitations

The delimitations of this study were as follow:

1. the cinematographical analysis was restricted to a two dimensional analysis of motion in the sagittal plane on a 25 metre ski jumping hill,
2. a sampling frequency of 150 frames/sec was utilized, and
3. the subjects included junior jumpers (11 subjects), and senior jumpers (4 subjects).

Definitions

Junior Jumper is defined by the organizing committee of the Thunder Bay Ski Jumps as an individual under the age of 18 years as of January 1 of the current competition year.

Senior Jumper is defined by the organizing committee of the Thunder Bay Ski Jumps as an individual 18 years of age and older as of January 1 of the current competition year.

Take-off Phase is the duration of time from the beginning of extension from the in-run position on the take-off ramp until the beginning of movement into a stable flight position. This phase usually covers the last 3 metres on the ramp and the first 7 metres of flight.

<u>Take-off</u> is the first instance of time when the middle of the jumper's boots are on the edge of the ramp.

<u>Pre-Flight</u> is the duration of time from take-off until the jumper has moved into the aerodynamic flight position.

<u>Relative Angles</u> (α, β, and γ) are the angles formed by two segments about the hip, knee, and ankle joints, respectively (Figure 1).

<u>Hip Angle</u> (α) is the relative angle about the hip joint as formed by the trunk and thigh. This angle is measured from the acromion process of the shoulder, the greater trochanter of the femur, and the femoral tibial articulation of the knee (Figure 1).

<u>Knee Angle</u> (β) is the relative angle about the knee joint as formed by the greater trochanter of the femur, the femoral tibial articulation of the knee, and the lateral maleolus of the fibula (Figure 1).

<u>Ankle Angle</u> (γ) is the relative angle about the ankle joint as formed by the femoral tibial articulation of the knee, the lateral maleolus of the fibula, and the toe of the boot (Figure 1).

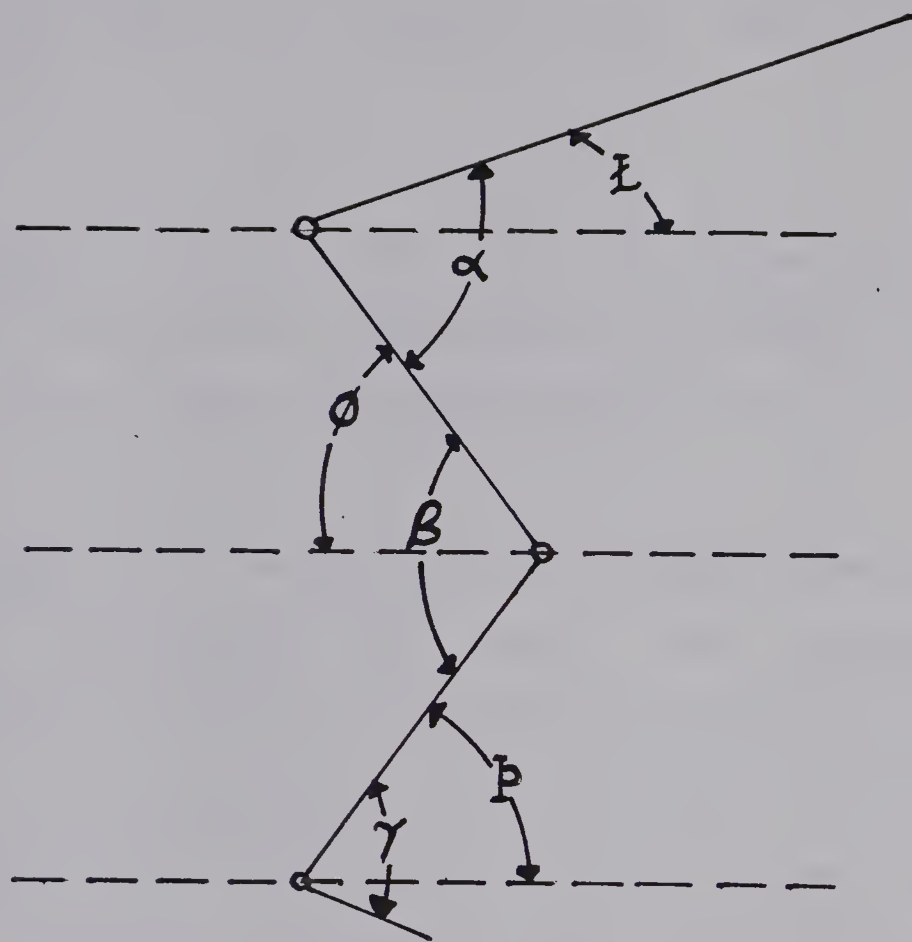


Figure 1

Definition of Relative and Absolute
Body Segment Angles

I. Relative Angles: Vector Dot Product

α = Relative Hip Angle
β = Relative Knee Angle
γ = Relative Ankle Angle

II. Absolute Angles: Arctan $\frac{Y_2 - Y_1}{X_2 - X_1}$

Ł = Absolute Trunk Angle
Ø = Absolute Thigh Angle
Þ = Absolute Leg Angle

Absolute Angles (Ł, Ø, and Þ) are the angles formed by the trunk, thigh, and leg respectively, with the horizontal (Figure 1).

Trunk Angle (Ł) is the absolute angle formed by the trunk (acromion process of scapula and greater trochanter of femur) and the right horizontal (Figure 1).

Thigh Angle (Ø) is the absolute angle formed by the thigh (greater trochanter of femur and femoral tibial articulation) and the left horizontal (Figure 1).

Leg Angle (Þ) is the absolute angle formed by the leg (femoral tibial articulation and lateral maleolus of the fibula) and the right horizontal (Figure 1).

CM Pathway (‡) is the angle formed by a line connecting two successive centres of mass and the right horizontal (Figure 2).

Ski to Horizontal Angle (§) is the angle formed by the ski to the horizontal (Figure 2).

Ski to Trunk Angle (£) is the angle of the trunk to the horizontal minus the angle of the ski to the horizontal (Figure 2).

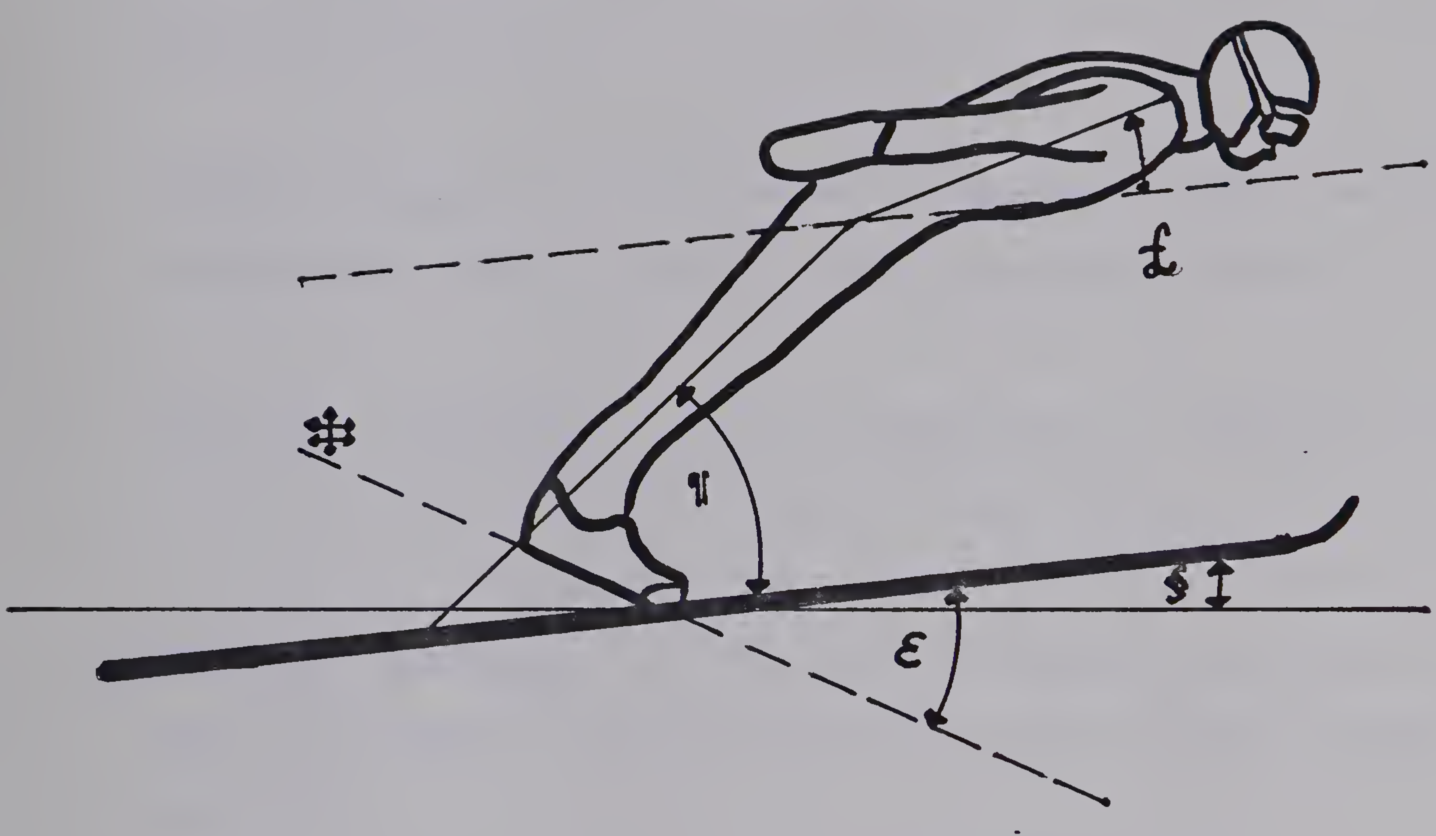


Figure 2

Definition of Body Angles in the Airborne Phase

£ = Ski to Trunk Angle

ε = Angle of Attack

§ = Ski to Horizontal Angle

¶ = Ski to Leg Angle

‡ = CM Pathway

Ski to Leg Angle (¶) is the angle between the ski and the leg (Figure 2).

Angle of Attack (ε) is the angle between the ski and the CM pathway (Figure 2).

Angular Velocity is the rate of change of relative angular displacement about the hip, knee, and ankle joints.

Take-off Velocity is the instantaneous velocity of the centre of mass of each subject at take-off.

Vertical Velocity is the instantaneous velocity of the centre of mass in the vertical direction of each subject at take-off.

Angle of Take-off is the angle subtended by the line connecting the centre of mass at take-off and the centre of mass at the next sampling and the right horizontal.

Ankle to CM Distance is the horizontal distance between the lateral maleolus of the fibula and the centre of mass at take-off.

Phase-lock is an electronic system which ensures frame for frame synchronization of the film between two intermittent pin-registered cameras at any set frame rate.

CHAPTER II

Review of Related Literature

Intrinsic to this study will be two phases of ski jumping, the take-off phase and the flight phase. There has been a limited amount of research concerning these two phases of ski jumping. However, the research completed has been beneficial to jumpers and coaches alike. The literature related to this study can be divided into two areas:
1. those studies concerned with the take-off phase in ski jumping, and 2. studies which examine the stable flight position of a ski jumper.

Literature Related to the Take-off Phase of Ski Jumping

Originating from little hops to overcome terrain obstacles, ski jumping has become a fascinating sports discipline attractive to both participants and spectators (Baumann, 1978). The first scientific interest taken in ski jumping dates from 1926 when Straumann published the first results of his observations and calculations concerning the flight paths of ski jumpers. Since that time detailed analysis of both the flight phase and take-off phase have been undertaken by sport researchers.

Baumann (1978) implied that the purposes for take-off are to give the centre of mass a maximum of normal

velocity, to produce a favourable body position at the jumps edge, and to initialize the suitable angular momentum for the forward rotation of the body immediately after the take-off point, but at the same time to avoid losses of tangential velocity. Campbell (1980) agreed with Baumann on the purposes of the take-off. He stated that the ski jumper should perform the take-off with the centre of mass in a forward position.

The jumping motion at take-off is caused by extension at the hip, knee, and ankle joints. In raising the centre of mass from a low position at take-off, the contribution from extension of the ankle joint represents approximately 10% of the total change in height, whereas extension about the knee and hip reflect approximately 65% and 25% respectively of the total elevation (Baumann, 1978; Campbell, 1980).

Baumann (1978) recorded a total of 400 training and competitive jumps at the 25th "4-Schanzen Tournee" in Oberstdorf, Germany. He concluded that the take-off movement was timed too early by about 40 milliseconds. Baumann reasoned that the take-off should be performed with the highest possible normal velocity. He measured the time interval from where peak normal velocity was achieved to the instant of take-off. Despite the fact that incorrect timing was distributed over the whole range of jumping lengths, the most qualified jumpers showed the least deviations from the optimum on the average. The optimum time difference was calculated to be zero at the time of take-off. Baumann

stated that correct timing at take-off's edge would be that point in time when the angular velocities of the hip, knee, and ankle were at a maximum. This timing was characteristic of the highly skilled jumpers. The less skilled jumper demonstrated peak angular velocities after the edge and the different maximum values did not coincide properly.

Campbell (1979) studied the take-off movement of fifteen subjects at the 1979 Pre-Olympic Games in Lake Placid. He found that the maximum angular velocities at the hip, knee, and ankle joints were reached at approximately the time of take-off (±.02 seconds). This finding was in general agreement with Baumann. However, Campbell only found a ten millisecond timing error between the point of maximum normal velocity and the point of take-off. Campbell's results also indicated some factors that related to distance jumped. These factors included:

1. maximum normal acceleration ($r=.61$),
2. maximum normal velocity ($r=.64$),
3. normal velocity at take-off ($r=.63$), and
4. direction of motion at take-off.

He also found that the absolute angle of the leg and the distance of the centre of mass in front of the base of support were related to performance.

Zubarev and Grozin (1975) recorded competitive jumps on film of elite and average Russian ski jumpers. They were particularly concerned with the movements about the hip, knee, and ankle joints. They found that:

1. elite jumpers showed a synchronized change of angular velocities,
2. average jumpers lacked this synchronization,
3. elite jumpers reached the take-off with maximum angular velocities of the hip, knee, and ankle joints coinciding at take-off,
4. average jumpers reached maximum angular velocities of the hip and knee joints after take-off, whereas the maximum angular velocity of the ankle coincided with take-off, and
5. the maximum velocities for the knee and hip joints were higher for the elite jumper.

The elite jumpers exhibited angular velocities of 15, 12, and 6 radians per second for the knee, hip, and ankle joints, respectively. The average jumpers had angular velocities of 12, 10, and 7 radians per second for the knee, hip, and ankle joints, respectively.

Komi et al (1974) investigated the take-off and flight phases of world class ski jumpers at the 1969 Salpausselka Games in Lahti, Finland. Their results indicated that:

1. there was a relationship between two height values along the flight path and distance jumped (r's=.60 & .70),
2. the height of the jumper soon after take-off directly affects the height in the latter part of the flight (r=.89),
3. linear velocity (averaged over the last 10 metres before take-off) was positively correlated with distance

(r=.54),

4. take-off distance negatively correlated with length of jump (r=-.42) as did take-off time (r=-.34), and
5. vertical velocity revealed a low positive correlation with distance (r=.39).

Komi suggested that the better jumpers initiated the take-off movement closer to the ramp's edge while completing the take-off in less time. Komi stressed the improvement of vertical lift at take-off.

Watanabe and Kawahara (1970) measured nine Olympic contenders in the take-off and flight phases of ski jumping. They reported relationships between approach time and flight time (r=-.64) and approach time and flight distance (r=-.60).

Tveit and Pedersen (1979) concluded that too much attention has been paid to the vertical acceleration in the take-off. They reported that it was more important to get from an aerodynamic position before the take-off into an aerodynamic position as early as possible after the take-off, with a minimum of air resistance. Komi et al (1974) found that in addition to maximizing the vertical lift, the take-off should also permit the jumper to immediately assume the optimal aerodynamic position.

Watanabe et al (1972) examined thirty Japanese and World Class ski jumpers on three different sized hills (60, 70, 90 metre hills). They reported a very high significant correlation between take-off velocity and flight distances

(r=.894). They declared that the best results were obtained only when the jumpers executed an effective take-off with very rapid take-off velocity. The high correlation could be a result of comparing take-off velocities and flight distances of the three different hills.

Gaskill (1980) concluded that in-run speed does have an effect on the length of flight. However, no correlations were reported, thus making comparisons to current literature impossible.

<u>Literature Related to the Flight Phase of Ski Jumping</u>

The earliest recorded research on the flight phase in ski jumping was conducted by R. Straumann in 1927. He used a scaled model placed inside a wind-tunnel to investigate "missing aerodynamic data". The scale model was positioned three different ways:

1. an extended body position,
2. erect to the hips and a bent torso (legs positioned at a 65° angle with air flow), and
3. a slightly arched position.

Results indicated that:

1. skiers should bend the torso to an angle of 28° to the direction of air flow immediately after take-off,
2. a stretched position with a 23° angle of forward lean (the angle between the legs and skis) provided the best aerodynamic efficiency,
3. bending the body facilitates forward rotation into the

strong forward leaning position, and

4. in general, all body positions were effective aerodynamically if the angle of the trunk with the direction of air flow was between 20° & 40°.

Tani and Iuchi (1971) also conducted wind-tunnel tests on a model. They used a life-sized model (1.73 m in height and 48 cm in shoulder breadth) to investigate the flight mechanical problems of ski jumping, with special consideration for achieving greater flight distances. By placing their results in equations which predicted flight distance, optimum angles of attack and body positions were identified. They found that:

1. a ski angle of attack of 20° to 30°,
2. a forward lean angle of 20°,
3. a hip bend angle of 22°, and
4. an arm angle (with trunk) of 165°,

produced maximum distance on a 70 m hill.

Nasimovich (1973) examined the elements of technique of the flight and combined the results of many researchers regarding optimal posture to the positions jumpers exhibited in competition. The calculations indicated that the winner of the competition was closer to the theoretically most favourable position in flight.

Krylov and Remizov (1975) examined the question of flight position by formulating a solution on an electronic computer as an optimal control problem. Results indicated that:

1. in jumps from medium hills (70-80m) a sufficiently high angle of attack (approximately 30°) in the first phase of flight yielded optimal trajectories, and
2. on longer hills, a lower angle of attack (15-23°) produced longer flights.

Summary of Literature Review

A review of ski jumping literature has demonstrated the importance of scientific analysis concerning the take-off and flight phases. Research has shown the importance of the take-off with respect to distance jumped. Wind-tunnel experiments have indicated the proper positioning of body and skis in the air.

There are still some questions that exist. What factor or factors are most important in ski jumping? What is the time factor between take-off and optimal flight position? Does the ski jumper who attains an aerodynamic position soon after take-off, fly the furthest? The answers to the above questions need to be determined.

CHAPTER III

Methodology

A ski jumping competition consists of three jumps. The first jump is a trial jump and is usually not considered in the final calculations unless something unforeseen happens (ie. weather). The second and third jumps are the competition jumps and are awarded points for style and distance and a winner is determined from the outcome of these points.

Subjects

Fifteen subjects were chosen from two different age levels of ski jumping as defined by the organizing committee of the Thunder Bay Ski Jumps. All competitors in the competition were used as subjects. For most subjects, the trial round and the two competitive jumps were filmed for subsequent analysis.

All competitors were dressed in their jumping suits, a helmet and goggles, socks and boots. Body segment markers were not placed on the subjects as these markers would move when the subjects were in the air and would make subsequent data analysis inaccurate.

Data Collection

Two Photo Sonics 1PL 16mm pin registered cameras were positioned with their optical axes perpendicular to the take-off plane on the 25 metre hill at Little Thunder, Thunder Bay, Ontario. The cameras were phase-locked to ensure synchronized data between the two cameras. Camera one recorded the take-off phase and camera two recorded the early flight phase. Both cameras were leveled and positioned on tripods 20 metres from the plane of action (Figure 3). The cameras were loaded with Kodak 7239 film (ASA 160). Camera speed was set at 150 fps for both trials. The frame rate was calibrated by using a Photo Sonics electronic internal timing light generator set at a frequency of 100 Hz. The cameras were operated with a shutter angle of 45 degrees, exposure time of 1/1200 second, focal length of 70 mm for camera one and 50 mm for camera 2, and an f stop of 2.2.

Prior to filming, a reference measure of 0.8 metres was filmed in the plane of motion of the skiers. The projected image of this measure during film analysis provided a known length which was used to calculate a conversion factor for converting from film measurements to real life distances.

Prior to and during filming, frequent light meter readings using a Pentax 1 degree Spotmeter VI were taken to account for changing light conditions.

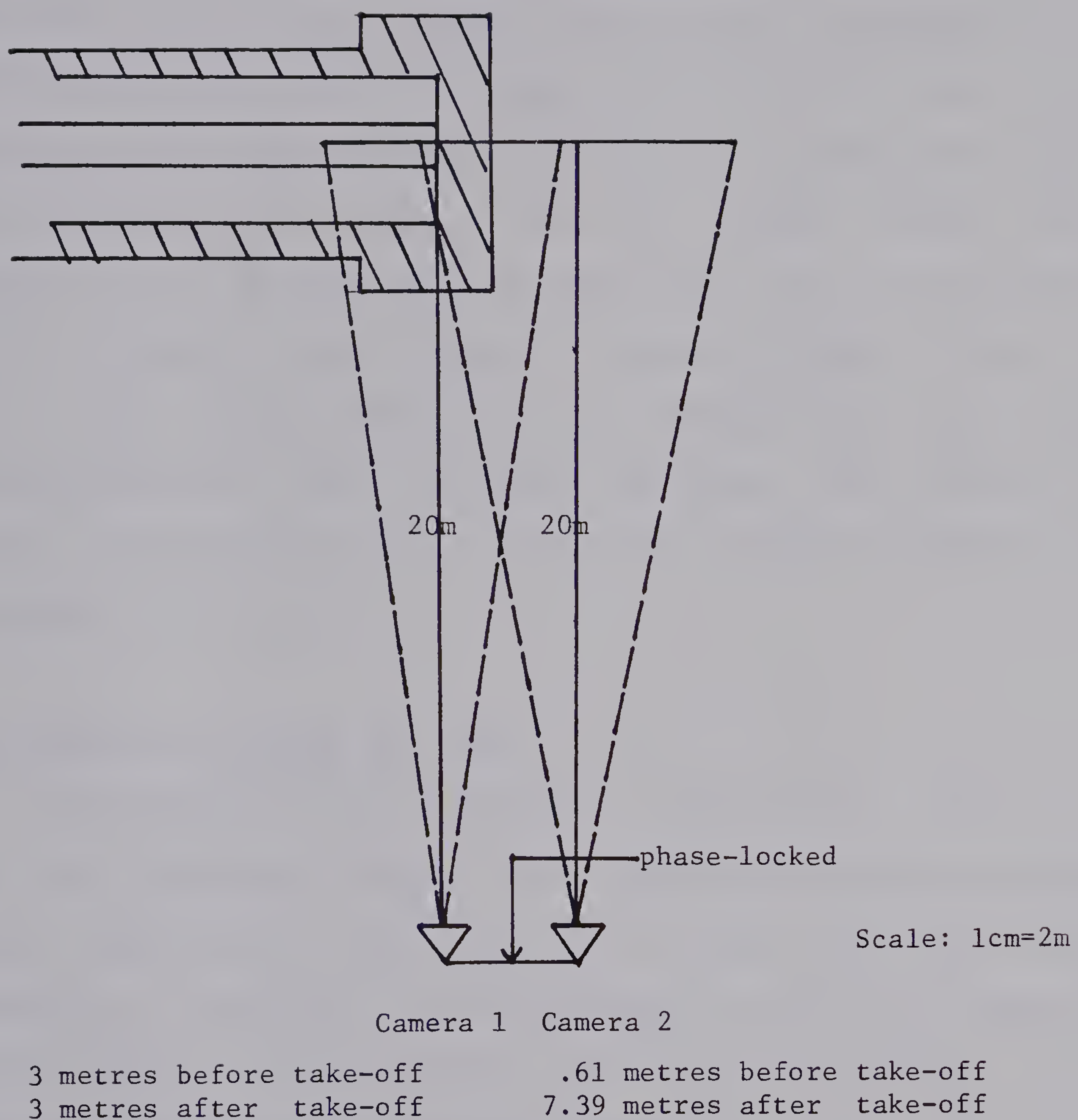


Figure 3

Camera Positions for Data Collection

Data Reduction

Film analysis was accomplished through the use of an electronic digitizing system. The film was projected onto a Bendix Digitizing Board (accuracy $\pm 2.54 \times 10^{-3}$ cm) by a Lafayette pin registered film analyzer. All subsequent input points were entered into a Hewlett Packard 9825B micro computer via a Hewlett Packard 9864A Digitizer and stored on magnetic computer tapes. Prior to extracting data from the film, the film analyzer was leveled and positioned perpendicular to the digitizing surface. The digitizing surface was leveled in all directions to assure proper film alignment.

Calculation of Centre of Mass

The Humanscale Anatomical Data (Diffrient, 1979) was used to calculate centre of mass locations for all body segment parameters used in this study. The data were adjusted to account for the weight of the ski jumper's helmet, boots, and skis. Table 1 presents the adjusted data for calculation of body centre of mass.

Calculation of Distances and Angles

Linear measurements were calculated by finding the displacement between two sets of X and Y coordinates and multiplying by the distance conversion factor.

Relative angles about the hip, knee, and ankle joints were calculated from the X and Y data points for each

Table 1

Adjusted Centre of Mass Data*

	percentage
Head	.0945
Trunk	.4130
Arm	.0596
Forearm	.0342
Hand	.0118
Thigh	.1894
Leg	.0812
Foot	.0442
Ski	.0721
Total	1.0000

* Data from Subject 6--mass=49.44 kg.

respective joint. The angle at the joint was calculated by the vector dot product.

The absolute angles were determined with respect to the horizontal. The trunk angle (Ł) and leg angle (Ø) were determined with respect to the right horizontal. The thigh angle (Þ) was determined with respect to the left horizontal. The arctangent rule was utilized to calculate the following angles:

1. angle of CM pathway,
2. angle of ski with horizontal,
3. angle of ski with trunk, and
4. angle of attack.

Derivation of Data

The data obtained from film consisted of displacement time functions. The raw data were then smoothed by a Butterworth 2nd order low pass filter (Walton, 1981). Corresponding velocity functions were calculated using finite differences (Miller & Nelson).

Data Analysis

The processed film was viewed and the take-off, which was contained in film one, was identified and marked with indelible ink. Then the two synchronized films were matched according to the timing marks on the edges of the film and edited. Film one contained the take-off movement and film two contained the early flight movement.

For both trials, every second frame of the take-off movement on film one and every second frame of the early flight movement on film two were digitized with input of the proximal and distal X and Y coordinates of the following body segments: 1. head and neck, 2. trunk, 3. arm, 4. forearm, 5. hand, 6. thigh, 7. leg, and 8. foot.

The Humanscale Anatomical Data (Diffrient, 1979) was used for all body segment parameters.

Timing Parameters

The timing parameters involved in this study included frame rate and time between frames. The frame rate was calculated by using the timing marks placed on the film at a

rate of one hundred per second. The light generator was set at 10 Hz and when the cameras attained their full framing rate they were reset to 100 Hz. The light generators were then reset to 10 Hz for the rest of the trial. The timing marks and the number of frames were counted for each trial. The frame rate was then found using the following calculation:

$$\text{Frame Rate} = \frac{\text{number of frames}}{\text{number of timing marks X .01 sec}}$$

The time between frames was then calculated by taking the inverse of the frame rate:

Time between Frames = 1/frame rate

<u>Accuracy and Consistency of Measurement</u>

Measurement accuracy and consistency were desired throughout this study. All data collection from the film was completed by the author using existing programs as well as newly written programs. An estimate of the total error involved in the digitizing process was performed. A known distance was digitized numerous times and the average absolute error was identified. This value served as the best *a priori* estimate of the error associated with each data point. To estimate the extent of variability of measuring a point on the digitizing surface, twenty repeated measures of various points were digitized. This value served as an indication of the degree of precision to which a point could

be measured on the screen. A subject was picked at random and the entire movement was re-digitized as a means of testing the consistency of the X and Y coordinates and the reliability of the digitizing sequence.

To check the accuracy of spatial coordinates the mean deviation between measured and computed coordinates for the reference measure points was determined. Using the pythagorean theorem the length of the reference measure was determined. A dependent samples t-test (Ferguson, 1976) was utilized to test for significant difference between the measured and computed lengths.

Statistics Procedures

Means, standard deviations, correlation matrices, and stepwise regression coefficients were calculated using the P-Series Biomedical Computer Programs (BMDP) developed at the University of California, Los Angeles.

Chapter IV

Results and Discussion

Introduction

This chapter presents the results and a discussion of the results found in this study. The first presentation will discuss the amount of error encountered, to be followed by a categorization of the subjects and the identification of the discrete events examined. An overview of the general movement patterns during the take-off and early flight phases of ski jumping will proceed. A presentation of the results found for each discrete event as well as the interrelationships between the variables is presented next. Finally, a discussion of the results will be deliberated.

Error Analysis

The error analysis presented from this study followed the guidelines of MacLaughlin et al (1976). A known distance was redigitized twenty times and the error estimate was ±3 mm for an 80 cm distance. Since the calculation of the distance involved digitizing two points, the total error was divided by two to attain an accuracy measure of ±1.5 mm. Next a number of discrete points were redigitized twenty times and the estimate of precision was ±2.4 mm. This value of 2.4 implies that any single point can be determined with a precision of ±2.4 mm. This measurement of precision is for

a well-defined point only. The landmarks of the human body are not as well defined, but with familiarity of the human body segments, the best *a priori* estimate of locating body landmarks is ±2.4 mm.

The reference marker was digitized in both films for each subject, for a conversion factor from film to real life distances. For film one, the mean conversion factor was 18.2±.09, and for film two, the mean was 25.3±.09. The reference marker was digitized for each subject because of editing and processing techniques employed on the film.

The relative angles about the hip and ankle were selected as best representing the reliability of the individual digitizer. The angles from forty frames of one individual were digitized twice and compared utilizing a t-test (Ferguson, 1981). The t-values obtained indicated no significant differences ($p>.05$) between the hip and ankle angles from one analysis to the next.

Categorization of Subjects

The sample for this study was the competitors on the Little Thunder Ski Jump hill in Thunder Bay, Ontario, on January 2, 1982. The competitors were placed into three categories according to age. For this study, two age groups were utilized. One group was comprised of senior jumpers and the other group was comprised of peewee and midget jumpers. The peewees and midgets were combined into a junior group because of the similarities in ages and distance jumped

(Table 2). The elite skiers were arbitrarily chosen from variables such as flight distance and timing at take-off.

Identification of Discrete Events

All of the events involved were identified by specific time intervals during and after take-off. These events were identified as take-off, +.11 seconds after take-off, +.22 seconds after take-off, and +.33 seconds after take-off.

Take-off and Flight Movement Patterns

Prior to the detailed analysis of the four discrete events, an overview of the entire movement is presented. Each figure includes a comparison between a junior average and a senior average skier. Comparisons are also made between a junior elite and a senior elite skier. Figure 4 presents the horizontal, vertical, and linear velocities of the centre of mass. Figure 5 presents the relative angular displacements about the hip, knee, and ankle. The absolute angular displacements of the trunk, thigh, and leg are presented in figure 6. The angle of attack and the angle of the CM pathway are presented in figure 7. Figure 8 presents the horizontal distance from the CM to the ankle. Figure 9 represents the angles of the ski to the horizontal, trunk, and leg. The relative angular velocities about the hip, knee, and ankle are presented in figure 10.

Table 2

Descriptive Data - 25m hill

Name	Age	Ht.(cm)	Wt.(kg)	Distance(m)		
JUNIOR						
H. Zilkowski	13	150	41.28	22.0	22.5	
B. Jackson	13	156	44.00	23.0	23.5	
J. Lockyer	13	143	39.01	19.0	21.5	
C. Rautio	12	138	30.39	18.0	19.0	
D. Fedorchuk	15	168	58.06	19.5	21.0	
J. Pastor	15	137	49.44	25.0	24.0	
C. Pastor	14	167	53.07	22.5	19.0	
R. Krys	15	167	64.41	22.5	20.5	
P. Martin	14	175	66.22	19.0	18.0	
C. Lang	14	150	40.82	24.0	24.0	
G. Hyatt	17	170	68.04	18.0	18.0	
SENIOR						
S. Kardas	30+	176	70.30	28.0	28.0	29.0
J. Buckley	18	175	68.04	28.0	28.5	27.0
T. Zilkowski	19	185	67.13	27.0	27.0	27.0
L. Collins	19	171	65.77	24.0	24.0	24.0

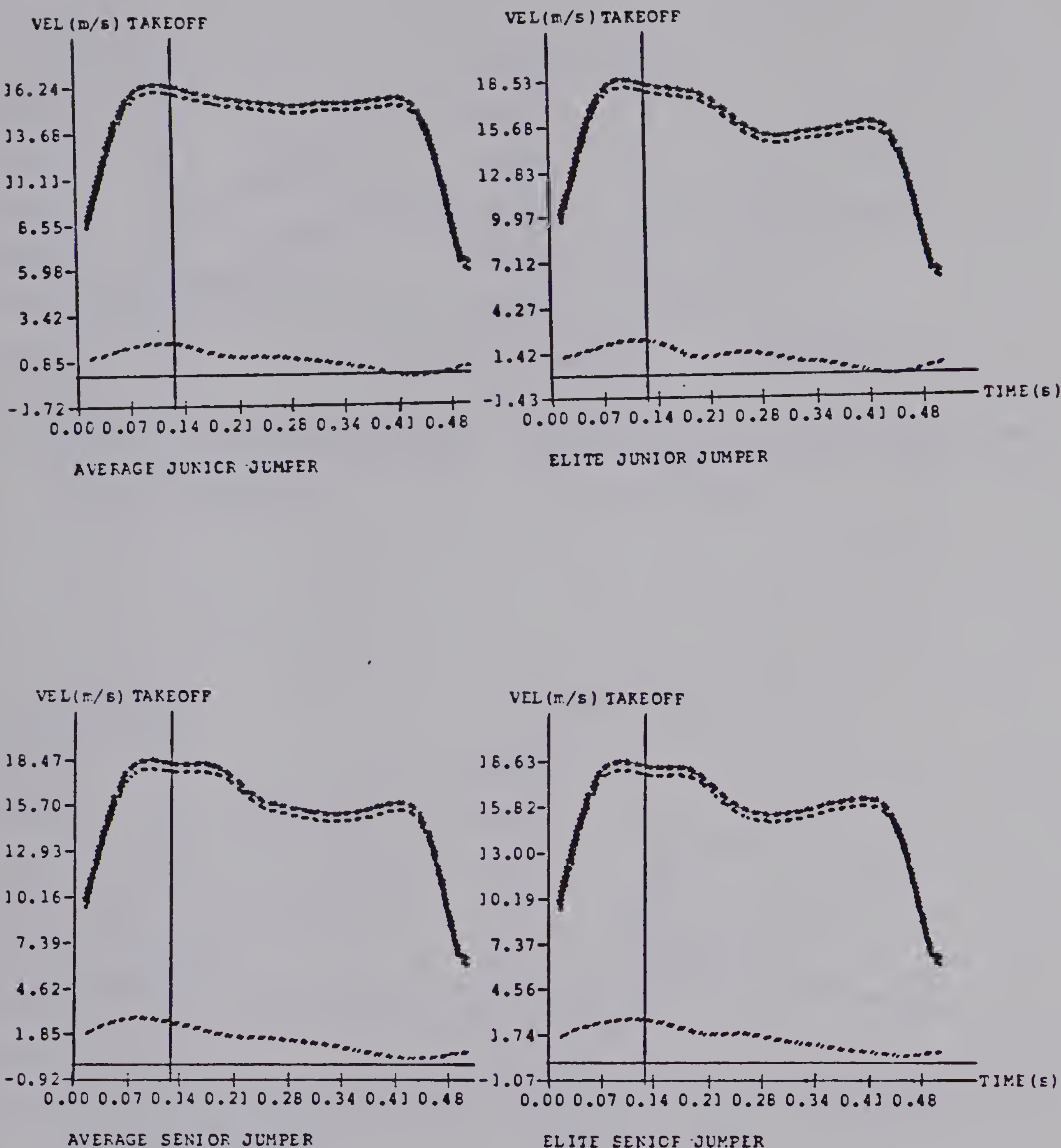


Figure 4

Horizontal (.), Vertical (,), and Linear (*) Velocities of the Centre of Mass for Selected Subjects

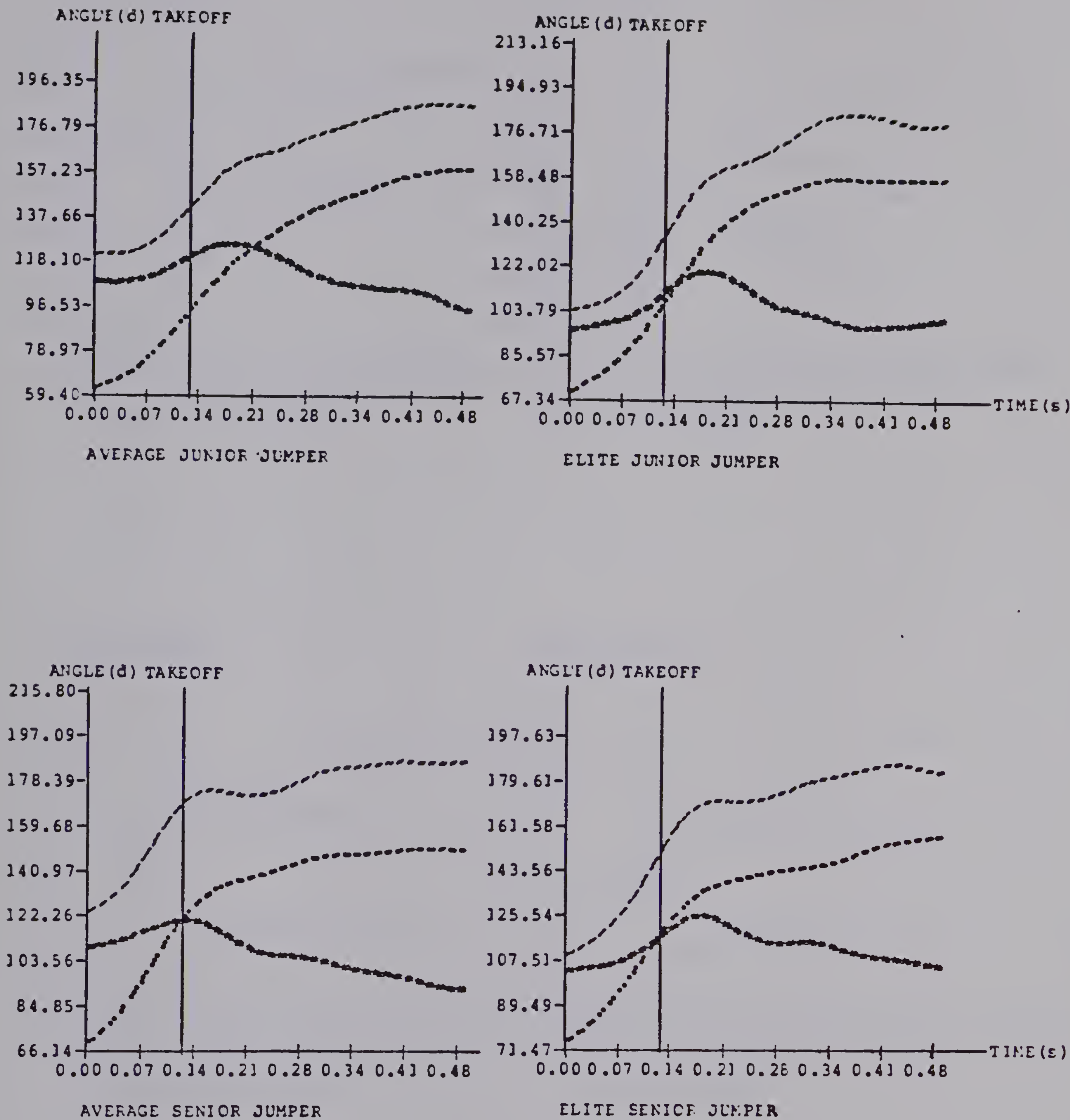


Figure 5

Relative Angular Displacements

about the Hip (.), Knee (,), and Ankle (*)

for Selected Subjects

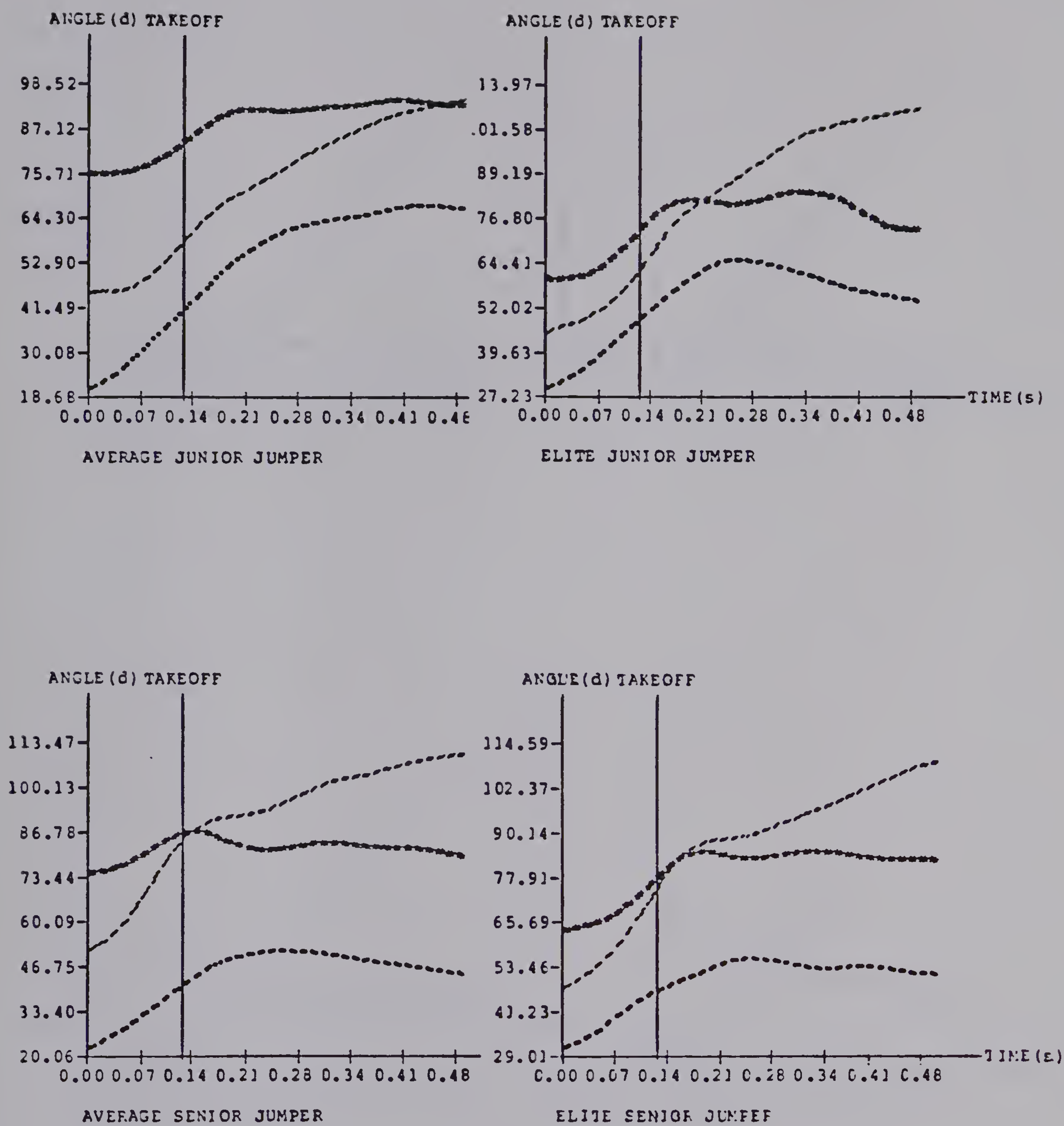


Figure 6

Absolute Angular Displacements

of the Trunk (.), Thigh (,), and Leg (*)

for Selected Subjects

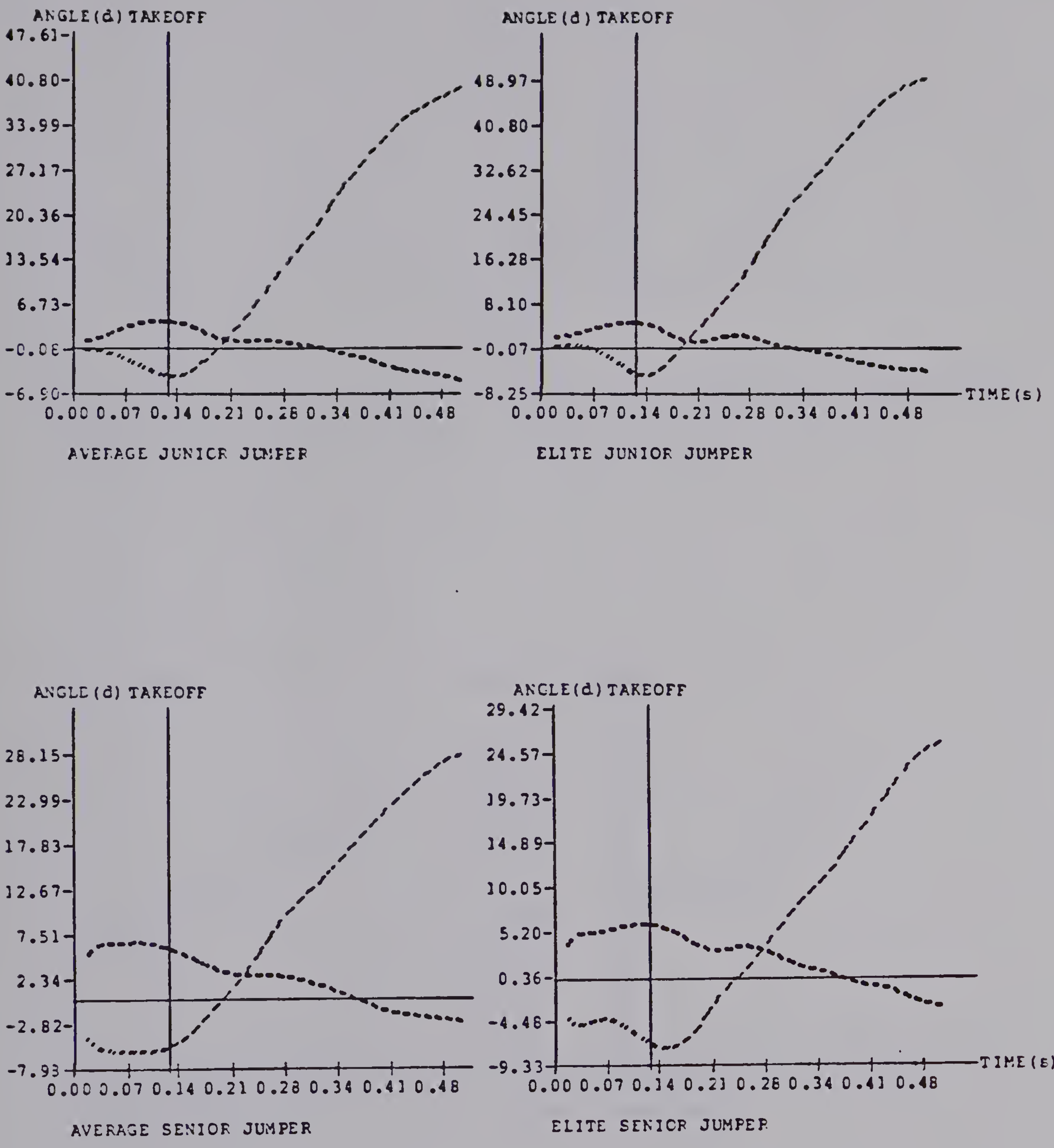


Figure 7

Angular Displacement of

the CM Pathway (.), and Angle of Attack (,)

for Selected Subjects

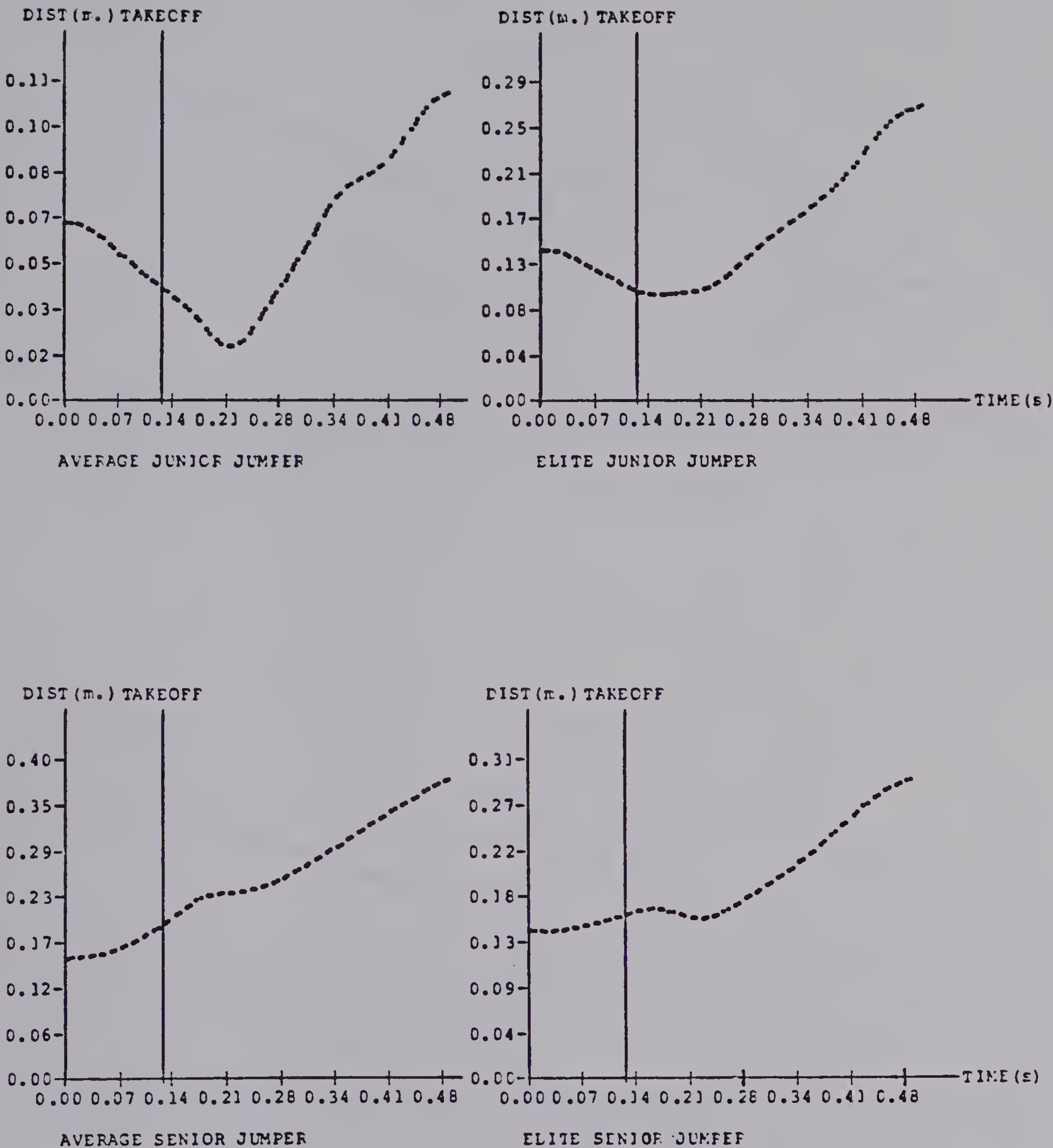


Figure 8

Horizontal Distance from CM to Ankle over Time

for Selected Subjects

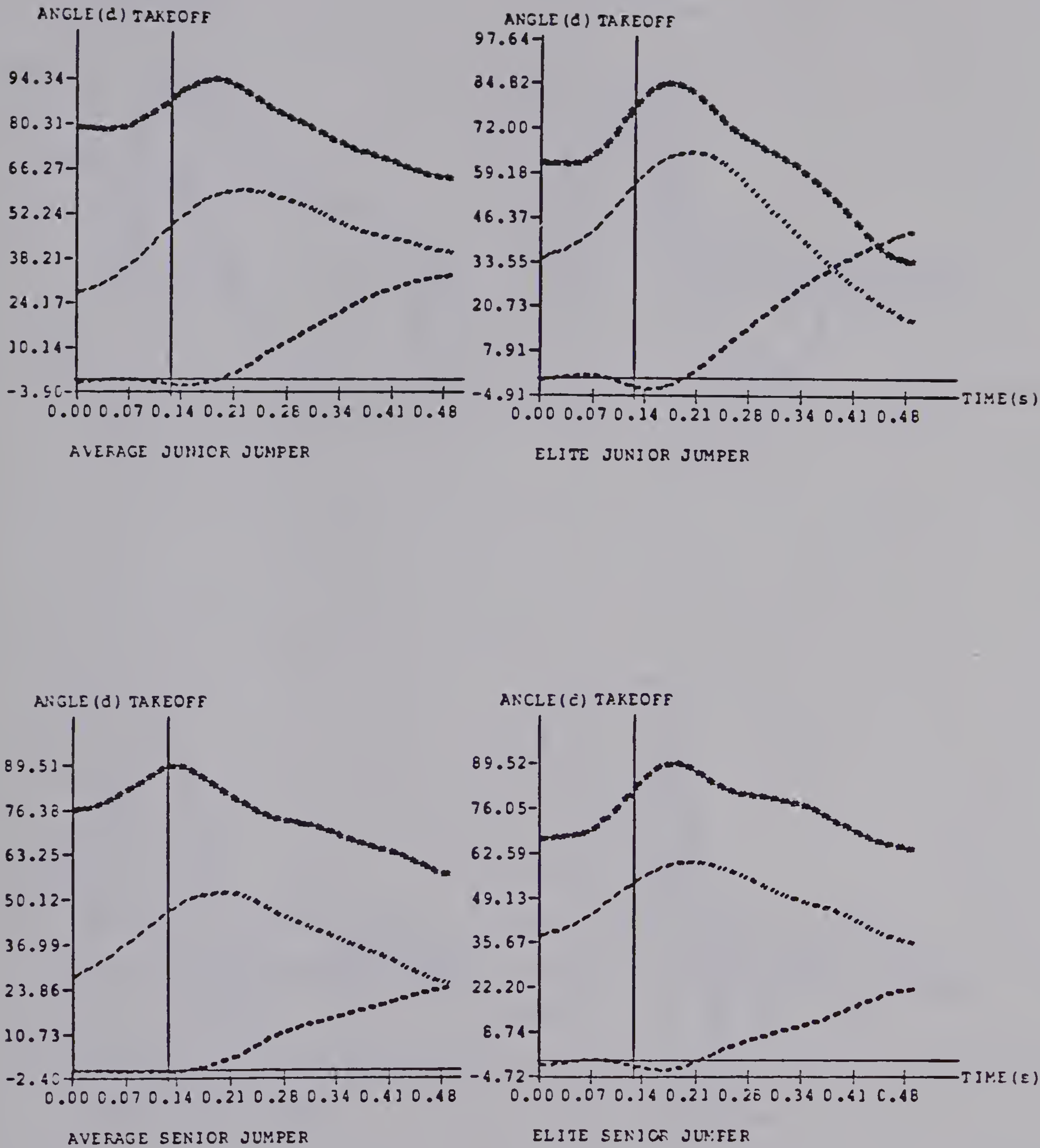


Figure 9

Angular Displacement of

Ski-Horizontal (.), Ski-Trunk (,), and Ski-Leg (*)

for Selected Subjects

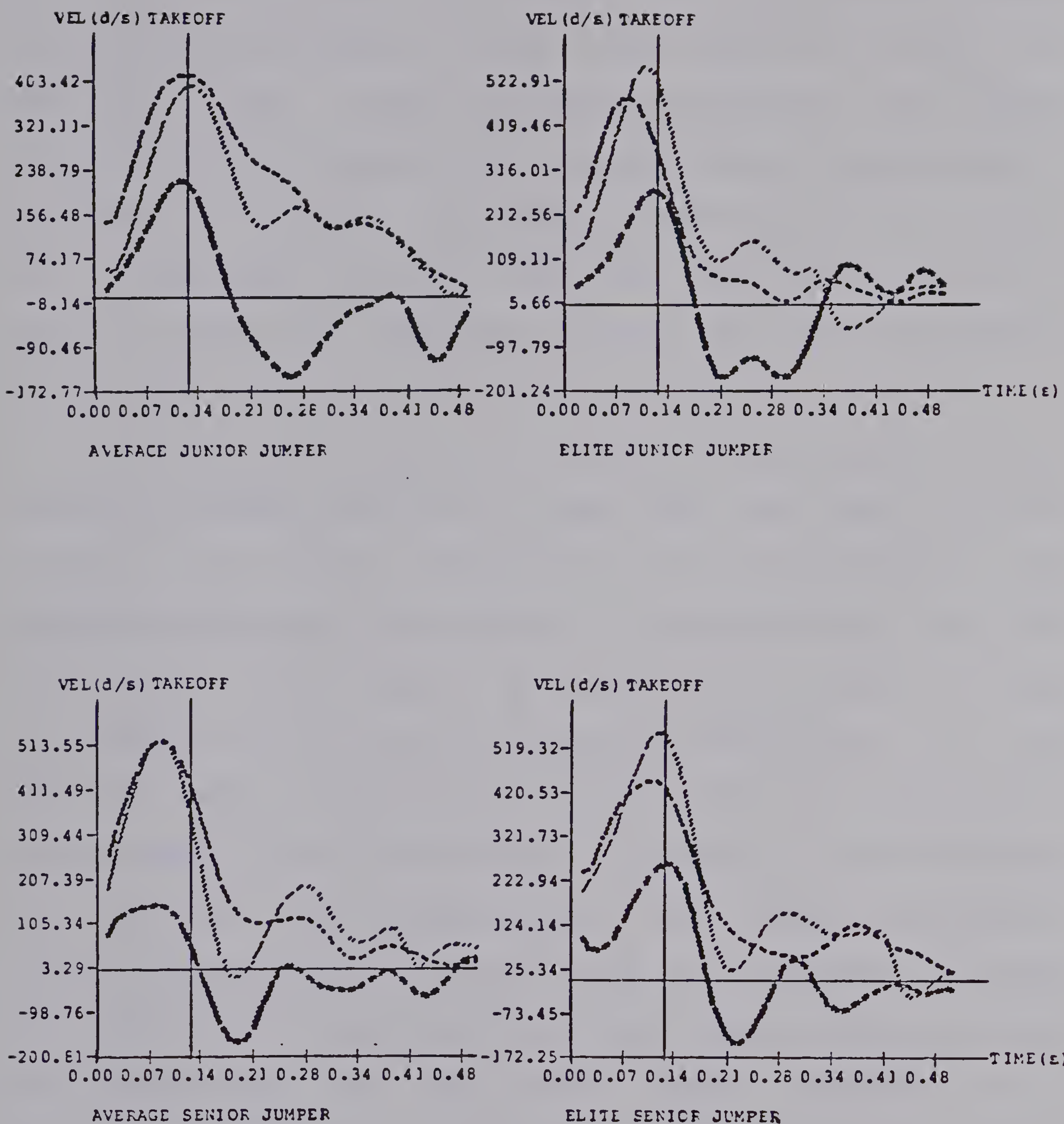


Figure 10

Relative Angular Velocities

at the Hip (.), Knee (,), and Ankle (*)

for Selected Subjects

It can be seen in figure 4 that the average senior skier attained a higher linear and vertical velocity at take-off. This trend continued throughout the flight movement and both senior and junior skiers experienced a decrease in linear velocity after take-off due to the forces of lift and drag, air flow, and the force of gravity. A similar trend was observed between the junior and senior elite skier.

In figures 5 and 6, it can be seen that the senior group had higher angles at the hip and knee and a lower angle at the ankle throughout the entire movement. The angular displacement increased at a fairly constant rate for both skiers up to a point .06 seconds before take-off. From this instant until take-off, angular displacements for the hip and knee increased at a more rapid rate. The angular displacement of the ankle did not increase as drastically as the hip and knee displacements. These large increases in angular displacement occurred as the skier rapidly extended his body in the jumping motion. After take-off the angles of the hip and knee for the senior jumper increased at a greatly reduced rate. The displacement of the ankle decreased as the skier moved his skis upward into the correct flight position. The junior skier increased the angular displacement of the hip and knee at a higher rate, suggesting the skier extended his trunk beyond an optimal position, thus exposing more surface area to the air. The increase in angular displacement of the hip and knee

continued for approximately .08 seconds after take-off. Then the skier increased his angular displacement of the hip and knee at a lower rate. The angular displacement of the ankle decreased shortly after take-off (.03 seconds) and continued to decrease as flight continued.

A similar trend occurred between the junior and senior elite skier, however, the junior skier maintained a smaller ankle angle than the senior skier throughout the movement.

Figure 7 shows the path of the CM for the senior jumper as being somewhat higher, and decreasing throughout the movement as compared to the junior skier. This movement would indicate that the senior skier has not elevated his trunk to a large degree, thus reducing the cross sectional area to the air flow pattern. The movement of the CM was also affected by lift and drag forces, as well as gravitational forces. The position of the junior skier indicated that extension of the trunk occurred until .06 seconds after take-off, thus raising the CM path angle. When the skier moved into a stronger flight position, by moving the trunk more forward over the skis, the CM path angle started to decrease. The angle of attack is comprised of the CM path angle and the angle of the skis to the horizontal. The senior jumper lifted his skis at take-off, thus resulting in a change of direction of the angle of attack. The movement of the skis was steady, thus resulting in a constant angle of attack. The junior skier allowed his skis to drop shortly after take-off and did not raise them above

the horizontal until .05 seconds after take-off occurred. The movement of the skis above the horizontal was not as steady and constant as the senior skier.

The senior elite skier exhibited a higher CM pathway over that of the junior elite but the angle of attack was very similar between the two skiers.

As shown in figure 8, there were vast differences between the junior and senior skier with reference to the horizontal distance from the CM to the ankle. The average junior skier extended considerably at the hip, thus raising the CM higher in the body and positioning it closer to the ankle in the horizontal direction. The average senior skier extended at the hip, and also at the knee, resulting in a forward position over the skis and a greater horizontal distance from the CM to the ankle. Similar differences were observed between the two elite skiers as well, however, the junior elite skier did not extend as much at the hip as did the average junior jumper.

Figure 9 represents the angles of the ski with the horizontal, trunk, and leg. The angles exhibited by both average skiers were similar. The angle of the ski to leg decreased shortly after take-off for the average senior skier and .03 seconds later for the average junior skier.

There were more dissimilarities among the elite skiers. The junior elite skier decreased the ski to leg angle much more than the senior elite skier. The junior skier also increased the angle of the ski to the horizontal

considerably more than did the senior skier. If the ski to the horizontal angle is too high, more cross sectional area of the ski is exposed to the drag forces. The ski to trunk angle for the junior skier was less than the ski to trunk angle for the senior skier as flight continued because of the ski to horizontal angle.

As can be seen in figure 10, the angular velocities of the hip, knee, and ankle between the average skiers were completely different. The senior skier had higher angular velocities about all three joints and attained these maximum values .05 seconds before take-off. The junior skier attained maximum velocities that were lower than the senior group and proceeded in the order of ankle, hip, and knee approximately ±.02 seconds from the take-off.

Both of the elite skiers exhibited similar trends. Their maximum angular velocities occurred ±.03 seconds from take-off and in the order of hip, knee, and then ankle.

The general movement patterns during the take-off and early flight phases of ski jumping can be seen by examining figures 4 through 10. A detailed analysis of the four discrete events of the take-off and early flight phases follows which presents a quantitative approach in examining these discrete phenomena. Further differences between groups were noted. These variations, although small in magnitude in some cases, were considered important because they indicated possible trends in technique. These differences at one discrete time period could influence the performance of the

skier in a later phase of flight.

Take-off

The first discrete event examined was the instant of take-off. At this point the athlete had the centre of his boots over the edge of the take-off ramp.

As can be seen in Table 3, there were many differences that existed between the senior and junior groups. The senior group exhibited a higher linear velocity (a difference of 1.08 m/sec, $p<.01$), as well as a higher vertical velocity (a difference of 0.42 m/sec, $p<.001$).

The relative angular displacements about the hip, knee, and ankle (114.24°, 158.51°, and 116.08° respectively) were higher for the senior group with a significant difference ($p<.01$) exhibited at the knee angle compared to those angles exhibited by the junior group (109.66°, 144.18°, and 112.68° respectively). The absolute angles of the trunk, thigh, and leg indicated different tendencies between the groups. The trunk angle was smaller for the senior group (38°) vs the junior group (43.73°), however the thigh angle was significantly larger ($p<.01$) for the senior group vs the junior group (76.23° vs 65.94°). The leg angle was also significantly larger ($p<.05$) for the senior group (82.27°) than for the junior group (78.25°).

Other variables that exhibited higher angular measures for the senior group compared to the junior group included the CM pathway (4.6° vs 3.25°, $p<.001$), the ski-leg angle

Table 3

Summary of Distances, Angles, And Velocities-Take-off

(Means and Standard Deviations)

	Senior		Junior	
	Mean	S.D.	Mean	S.D.
Flight Distance (m)	26.875	1.75	21.07***	2.35
Linear Velocity (m/sec)	17.29	0.93	16.21**	0.85
Vertical Velocity (m/sec)	1.28	0.29	0.86***	0.24
RELATIVE ANGLES (deg)				
Hip	114.24	10.75	109.66	19.41
Knee	158.51	9.32	144.18**	15.74
Ankle	116.08	2.48	112.68	6.84
ABSOLUTE ANGLES (deg)				
Trunk	38.00	6.67	43.73	10.51
Thigh	76.23	6.56	65.94**	12.49
Leg	82.27	3.96	78.25*	6.12
MOTION OF CENTRE OF MASS				
CM Path (deg)	4.60	0.92	3.25***	0.86
Attack Angle (deg)	-7.16	1.46	-6.64	1.00
CM-Ankle Distance (m)	0.15	0.035	0.09**	0.053
SKI-SEGMENT MEASURES (deg)				
Ski-Horizontal	-2.55	0.74	-3.39**	0.56
Ski-Trunk	40.57	6.77	47.11*	10.37
Ski-Leg	84.84	3.64	81.63	5.82
ANGULAR VELOCITIES (deg/sec)				
Hip	365.41	87.75	341.36	110.50
Knee	347.95	146.92	355.28	113.08
Ankle	104.00	100.26	167.08	79.31

*Difference Significant at $p<.05$
**Difference Significant at $p<.01$
***Difference Significant at $p<.001$

(84.84° vs 81.63°), and the ski to horizontal (-2.55° vs -3.39°, $p<.01$). Lower angular measures for the senior group vs the junior group included the ski to the trunk (40.57° vs 47.11°, $p<.05$), and the angle of attack (-7.16° vs -6.64°).

The horizontal distance from the CM to the ankle was significantly greater ($p<.01$) for the senior group (0.15 metres) compared to the junior group (0.09 metres).

Maximum angular velocities of the hip and knee were approximately equal for both groups. The senior group had a slightly higher hip velocity than the junior group (365.41°/sec and 341.36°/sec respectively) and a slightly lower knee velocity (347.95°/sec and 355.28°/sec respectively). The velocity at the ankle was much lower for the senior group than for the junior group (104°/sec and 167.08°/sec respectively). The maximum angular velocities occurred approximately at the instant of take-off (±.05 seconds) for most jumpers in both groups.

+.11 Seconds After Take-off

The second discrete event that was investigated was the position and motion of the ski jumper at a time 0.11 seconds after take-off. At this time the jumper had cleared the take-off platform and was preparing to move into an aerodynamic flight position.

The relative angular displacements indicated that a large extension had occurred at the hip and knee joints for both groups. It can be seen in Table 4 that the hip and knee

Table 4

Summary of Distances, Angles, And Velocities-+.11 sec

(Means and Standard Deviations)

	Senior		Junior	
	Mean	S.D.	Mean	S.D.
RELATIVE ANGLES (deg)				
Hip	133.03	6.31	128.56	26.10
Knee	170.31	4.69	163.59**	5.75
Ankle	110.52	6.10	113.61	4.03
ABSOLUTE ANGLES (deg)				
Trunk	45.86	5.13	54.78***	7.83
Thigh	87.17	3.99	78.33***	6.90
Leg	83.14	4.25	85.26	4.45
MOTION OF CENTRE OF MASS				
CM Path (deg)	0.14	2.16	-0.61	2.14
Attack Angle (deg)	4.58	4.62	2.93	4.45
CM-Ankle Distance (m)	0.18	0.05	0.08***	0.062
SKI-SEGMENT MEASURES (deg)				
Ski-Horizontal	4.71	3.28	2.31	3.76
Ski-Trunk	41.15	6.61	52.47***	7.51
Ski-Leg	79.28	6.36	82.95	4.56
ANGULAR VELOCITIES (deg/sec)				
Hip	69.95	55.39	113.99	115.16
Knee	50.32	61.40	60.86	54.45
Ankle	-113.16	57.35	-120.23	58.70

*Difference Significant at $p<.05$
**Difference Significant at $p<.01$
***Difference Significant at $p<.001$

angles were greater for the senior group (133.03° and 170.31° respectively) than for the junior group (128.56° and 163.59° respectively). The knee angle showed a significant difference ($p<.01$). One of the objectives of the skier was to move his skis into an aerodynamic position as soon as possible and this fact was evidenced by the small change in angular position of the ankle from take-off, for both groups (110.52° (senior), 113.61° (junior)).

The absolute angles of the trunk and thigh showed significant differences ($p<.001$) between the two groups (45.86° and 87.17° respectively (senior), 54.78° and 78.33° respectively (junior)). There was not much difference in the leg angle between the groups (83.14° (senior), 85.26° (junior)).

Similar tendencies were found at this time interval as were observed at take-off for the following angular measures. Higher angular measures for the senior group were demonstrated for the CM pathway (0.14°), the ski to the horizontal (4.71°), and the angle of attack (4.58°) than for the junior group (-0.61°, 2.31°, and 2.93° respectively). Lower angular measures included the ski to the trunk (41.15° (senior), 52.47° (junior), $p<.001$), and ski to the leg (79.28° (senior), 82.95° (junior)).

The CM to ankle distance was also significantly greater ($p<.001$) for the senior group (0.18 metres) than for the junior group (0.08 metres).

The angular velocities indicated a movement into stable flight. The hip and knee velocities decreased to maintain the angular positions for flight, whereas the ankle angle decreased dramatically. The decrease in ankle velocity can be explained by the fact that the skis were being elevated to an aerodynamic position, thus causing a decrease in ankle angular position.

+.22 Seconds After Take-off

The third discrete event that was examined was the instant 0.22 seconds after take-off. At this time the jumper had completed most of the extension and was moving into a favourable flight position.

Table 5 shows similar differences between the two groups as did the previous table. The relative angular displacements for the hip and knee increased slightly from the previous time event, with the knee angle again showing a significant difference ($p<.01$). The hip angle was 140.53° for the senior group and 142.25° for the junior group. The knee angle was 176.96° for the senior group and 172.53° for the junior group. The ankle angle decreased for both groups as the skis were being elevated into an aerodynamic position (100.72° (senior), 103.19° (junior)).

The trunk and thigh angle were also significantly different ($p<.001$) for the senior group (44.88° and 95.65° respectively) than for the junior group (55.02° and 87.23° respectively).

Table 5

Summary of Distances, Angles, And Velocities-+.22 sec

(Means and Standard Deviations)

	Senior		Junior	
	Mean	S.D.	Mean	S.D.
RELATIVE ANGLES (deg)				
Hip	140.53	5.55	142.25	8.92
Knee	176.96	1.77	172.53**	5.04
Ankle	100.72	6.27	103.19	7.48
ABSOLUTE ANGLES (deg)				
Trunk	44.88	4.73	55.02***	7.79
Thigh	95.65	3.85	87.23***	6.35
Leg	83.32	4.35	85.34	6.21
MOTION OF CENTRE OF MASS				
CM Path (deg)	-0.14	0.86	-1.97***	0.82
Attack Angle (deg)	16.14	4.98	15.68	8.21
CM-Ankle Distance (m)	0.24	0.051	0.13***	0.067
SKI-SEGMENT MEASURES (deg)				
Ski-Horizontal	16.00	4.47	13.71	8.37
Ski-Trunk	28.88	7.73	41.31***	8.15
Ski-Leg	67.32	4.62	71.49	7.79
ANGULAR VELOCITIES (deg/sec)				
Hip	40.18	33.94	53.10	43.77
Knee	3.94	49.64	64.74**	42.76
Ankle	-77.57	34.70	-89.26	63.14

*Difference Significant at p<.05
**Difference Significant at p<.01
***Difference Significant at p<.001

The senior group also showed significant differences ($p<.001$) for the CM pathway and ski to trunk angle (-0.14° and 28.88° respectively) than for the junior group (-1.97° and 41.31° respectively). Differences were also noted for the ski to the horizontal angle (16° (senior), 13.71° (junior)), the ski to leg angle (67.32° (senior) 71.49° (junior)). The angle of attack was similar for both groups (16.14° (senior), 15.68° (junior)). The CM to ankle distance was again significantly different ($p<.001$) for the senior group (0.24 metres) than for the junior group (0.13 metres).

The angular velocities indicated the slight angular positional change in the athletes to ensure stabilized flight.

<u>+.33 Seconds After Take-off</u>

The final discrete event measured was the instant 0.33 seconds after take-off. At this time, the ski jumper should be in a favourable flight position and should maintain the position until landing.

It can be seen in Table 6 that the relative angular displacement changed very little from the previous phase. The hip and knee angles were slightly larger for the senior group (146.1° and 177.06° respectively) than for the junior group (144.69° and 175.92° respectively). The ankle angle decreased slightly from the previous phase with the senior group possessing a smaller angle (94.59°) than the junior group (98.28°).

Table 6

Summary of Distances, Angles, And Velocities-+.33 sec

(Means and Standard Deviations)

	Senior		Junior	
	Mean	S.D.	Mean	S.D.
RELATIVE ANGLES (deg)				
Hip	146.10	6.31	144.69	9.75
Knee	177.06	2.93	175.92	3.52
Ankle	94.59	6.59	98.28	7.19
ABSOLUTE ANGLES (deg)				
Trunk	42.95	4.61	52.38***	8.90
Thigh	103.16	4.07	92.31***	6.31
Leg	79.45	4.07	84.64*	7.76
MOTION OF CENTRE OF MASS				
CM Path (deg)	-3.00	1.04	-5.00	0.72
Attack Angle (deg)	28.89	7.28	29.40	11.81
CM-Ankle Distance (m)	0.31	0.05	0.16***	0.073
SKI-SEGMENT MEASURES (deg)				
Ski-Horizontal	25.89	6.71	24.39	12.18
Ski-Trunk	17.05	10.02	27.98*	12.95
Ski-Leg	53.56	6.23	60.25	11.17
ANGULAR VELOCITIES (deg/sec)				
Hip	32.47	22.28	2.57*	42.21
Knee	-22.59	31.22	15.46*	37.67
Ankle	-69.71	49.17	-22.72	80.71

*Difference Significant at $p<.05$
**Difference Significant at $p<.01$
***Difference Significant at $p<.001$

Consistent with the position of the previous phase, the senior group exhibited significant differences ($p<.001$) for the trunk (42.95°) and the thigh (103.16°) from the junior group trunk (52.38°) and thigh (92.31°). The leg angle for the senior group was also significantly lower (79.45°, $p<.05$) than for the junior group (84.64°).

The CM pathway was higher for the senior group (-3°) than for the junior group (-5°). The ski to trunk angle was also significantly lower ($p<.05$) for the senior group (17.05°) than for the junior group (27.98°). The ski to the horizontal angle and the attack angle were similar for both groups (25.89° and 28.89° respectively (senior), 24.39° and 29.4° respectively (junior)). The ski to leg angle was smaller for the senior group (53.36°) than for the junior group (60.25°).

The CM ankle distance was also significantly higher ($p<.001$) for the senior group (0.31 metres) than for the junior group (0.16 metres).

The angular velocities indicated positioning of the body and skis in flight and changed little from the previous phase.

Interrelationships Among Variables

In this study, stepwise regression was utilized to determine a predictor or predictors for distance jumped. This section presents the significant relationships of the variables studied for both groups at each discrete event as

well as the predictors when both groups were combined.

Take-off

The significant variables that contributed to distance jumped for the junior group were the knee angle, the CM pathway, and the angle of the ski to the trunk. The correlation coefficient (r) calculated was .75 ($p<.01$)(Table 7). The intercorrelation amongst the three variables were low ($r=-.27$, - .39, and .18). A low intercorrelation between variables indicated that the variables entered into the regression equation do indeed each contribute, to the dependent variable (Kerlinger & Pedhazur, 1973).

Table 7 presents the significant contributors for the senior group to distance jumped and the intercorrelations amongst the variables. It was found that angular velocity of the knee and hip combined for an 'r' value of .88 ($p<.01$). The intercorrelation between the two values was moderate ($r=-.68$).

When the two groups were combined, the significant variables were quite different from each individual group. Vertical velocity and the angle of attack combined for an 'r' value of .77 ($p<.01$). The intercorrelation between the two predictors was quite high ($r=.82$).

+.11 Seconds After Take-off

The junior group had only one contributor to distance

Table 7

Summary of Results for Stepwise Regression

Take-off

Group	Factors & Intercorrelations				Correlation Coefficient
Junior (N=22)	Knee Angle	1.00			.75*
	CM Pathway Angle	-.27	1.00		
	Ski to Trunk Angle	-.39	.18	1.00	
Senior (N=12)	Angular Velocity of Hip	1.00			.88*
	Angular Velocity of Knee	-.68	1.00		
Both (N=34)	Vertical Velocity	1.00			.77*
	Angle of Attack	.82	1.00		

*significant at .01 level

jumped at this time. The angle of the ski to the horizontal was significant at $p<.01$, with an 'r' value of .58.

The senior group, on the other hand, showed that vertical velocity and the CM pathway were significant predictors at $p<.01$, with an 'r' value of .94. The intercorrelation between the two variables was very low ($r=.06$) (Table 8).

Upon comparing both groups, vertical velocity, linear velocity, CM pathway, the angle of attack, and the angular velocity of the hip combined for sigificance at $p<.01$, with an 'r' value of .89. The intercorrelations did not show very high values (Table 8).

+.22 Seconds After Take-off

At this time, the angle of the ski to the horizontal and angular velocity of the ankle were significant predictors for distance jumped in the junior group ($r=.8$, $p<.01$). The intercorrelation was quite low ($r=.11$)(Table 9).

The senior group demonstrated the CM pathway and angle of the ski to the leg to be significant predictors for distance jumped ($r=.97$, $p<.01$). The intercorrelation was moderate ($r=-.47$) (Table 9).

The CM pathway and the angle of attack, as evidenced in the previous event when both groups were combined, were important predictors for distance jumped. These significant contributors ($p<.01$) combined with the angle of the ski to the trunk for an 'r' value of .83. The intercorrelations

Table 8

Summary of Results for Stepwise Regression

.11 Seconds After Take-off

Group	Factors & Intercorrelations						Correlation Coefficient
Junior (N=22)	Ski to Horizontal Angle						.58*
Senior (N=12)	Vertical Velocity	1.00					.94*
	CM Pathway Angle	-.06	1.00				
Both (N=34)	Vertical Velocity	1.00					.89*
	Linear Velocity	-.53	1.00				
	CM Pathway Angle	.4	-.47	1.00			
	Angle of Attack	.03	-.26	.57	1.00		
	Ang. Vel. Hip	-.02	.05	-.07	-.01	1.00	

*significant at .01 level

Table 9

Summary of Results for Stepwise Regression

.22 Seconds After Take-off

Group	Factors & Intercorrelations	Correlation Coefficient
Junior (N=22)	Ski to Horizontal Angle 1.00 Angular Velocity of Ankle .11 1.00	.80*
Senior (N=9)	CM Pathway Angle 1.00 Ski to Leg Angle -.47 1.00	.97*
Both (N=32)	CM Pathway Angle 1.00 Angle of Attack -.11 1.00 Ski to Trunk Angle -.21 .50 1.00	.83*

*significant at .01 level

were not very high (Table 9).

+.33 Seconds After Take-off

The junior group demonstrated the significance of the angle of the ski to the horizontal and the angular velocity of the ankle to be successful predictors for distance jumped with significance at $p<.01$ and an 'r' value of .82. The intercorrelation between the two variables was quite low ($r=-.12$).

The senior group exhibited the same significant contributors as in the previous phase with the CM pathway and the angle of the ski to the leg being significant at $p<.01$ ($r=.94$). The intercorrelation was moderately high ($r=-.6$).

Overall, the significant contributors were the CM pathway, the ankle angle, the angle of the ski to the trunk, and linear velocity. The 'r' value was .92 ($p<.01$). The intercorrelations were not very high at all (Table 10).

Discussion

In this study, the kinematic factors of the take-off and early flight phases of ski jumping were examined in order to identify those factors which were important for the successful completion of long flight in ski jumping. Two groups were utilized to determine which factors could successfully predict distance jumped. Four discrete phenomena which occurred during take-off and early flight

Table 10

Summary of Results for Stepwise Regression

.33 Seconds After Take-off

Group	Factors & Intercorrelations	Correlation Coefficient
Junior (N=22)	Ski to Horizontal Angle 1.00 Angular Velocity of Ankle -.12 1.00	.82*
Senior (N=9)	CM Pathway Angle 1.00 Ski to Leg Angle -.06 1.00	.94*
Both (N=32)	CM Pathway Angle 1.00 Ankle Angle .01 1.00 Ski to Trunk Angle -.32 -.07 1.00 Linear Velocity .08 -.17 .30 1.00	.92*

*significant at .01 level

phases were isolated to aid in the identification of technique similarities and differences between groups in competitive ski jumping.

There was a significant difference at take-off of the absolute leg angle between the two groups. The senior group demonstrated a higher leg angle ($p<.05$). Recent literature (Campbell, 1979; and Marchiori et al, 1982) indicated the significant contribution of the leg angle to distance jumped. They implied that the lower the leg angle at take-off the further the jumper travelled in the air. The rather high values recorded by both the senior and junior groups indicated the straight up posture used by both groups. The take-off ramp in the present study was calculated to be 1° below horizontal, whereas in the previous studies, the angle of the ramp was -10°. The difference in the angles at take-off could account for the greater angles of the leg in the present study.

The knee angle for the senior group was significantly higher than the knee angle of the junior group. The hip angle was also slightly higher for the senior group. The larger angles demonstrated by the senior group indicated that their CM was more forward at the point of take-off. This assumption was evident with the angle of the thigh being significantly higher for the senior group as well as the CM to ankle distance. This trend was demonstrated continually throughout the analysis. At take-off, the difference in the CM to ankle distance could be attributed

to the difference in the thigh angle.

It was observed that the senior jumpers demonstrated a significantly higher linear and vertical velocity at take-off. The higher linear velocity could be attributed to a lower trunk angle, thus reducing the cross sectional area exposed to air resistance. The higher vertical velocity could be explained by the fact that the senior group was crouched more at take-off, thereby enabling them to extend to a larger degree and attain a higher vertical impulse.

The CM pathway for the senior group was also significantly higher at take-off. The senior group was in a more advantageous position to convert linear velocity into vertical velocity and thus increase their lift. This higher CM pathway at take-off could influence the direction and length of the flight, and this is evidenced by the longer flight distances achieved by the senior group.

Grozin (1975) found that superior skiers reached maximum angular velocities for the hip, knee, and ankle at take-off. He also provided optimal angular velocities. In the present study, it was found that maximum angular velocities for both groups, did not always occur at take-off (±.05 seconds) and that they were not as high as suggested by Grozin. The elite skiers in both groups, however, had maximum angular velocities at the moment of take-off (±.02 seconds), and proceeded in the manner of hip, knee, and then ankle. The other jumpers did not exhibit such tendencies. Figure 10 shows that the average junior jumper had peak

angular velocities in the manner ankle, knee, and then hip, and the average senior jumper had peak angular velocities occurring at the same time.

At .11 seconds after take-off, the CM to ankle distance indicated that the senior group was in a more forward leaning position. The absolute thigh angle was significantly higher and the absolute trunk angle was significantly lower for the senior group, thus decreasing air resistance and increasing the forward leaning posture.

The ski to trunk angle was also significantly lower for the senior group, thus reducing even more the cross sectional area to air resistance.

The senior group enjoyed an improved aerodynamic flight position compared to the juniors. At this time, the actions of the junior group at take-off affected their flight appearance. The junior group extended considerably at the hip and developed an upright posture. This upright posture decreased the CM to ankle distance and increased the cross sectional area to air resistance. The absolute thigh angle indicated a sitting back posture. This sitting back posture could stem from the inability of the juniors to cope with the gravitational forces exerted on them as they pass through the transition slope and on to the take-off. Also, the early extension of the trunk did not enable them to extend more about the knee, thus facilitating a sitting back posture.

These faults at take-off by the junior group were evidenced at .11 seconds after take-off. The juniors still retained a high trunk angle and a high ski to trunk angle. These high angles increased the cross sectional area of the body to air resistance. The lower velocities at take-off for the juniors resulted in a lower CM path angle and angle of attack.

At .22 and .33 seconds after take-off, similar results between the groups occurred. The extensions about the hip and knee had stabilized and the ankle angle decreased to elevate the skis. The senior group still exhibited a greater thigh angle and CM to ankle distance. They also exhibited lower angles at the trunk and leg, as well as the ski to trunk angle. The CM path followed a lower slope gradient for the seniors, thus enabling them to fly further distances. Again, the actions at take-off determined the position of the jumper throughout the flight path.

The stepwise regression results indicated different predictors at take-off for distance jumped for each group. The junior group established the importance of the knee angle, the CM pathway, and the ski to trunk angle as being predictors for distance jumped. There were significant differences among the groups with respect to the three angles. There was also a significant difference among the groups with respect to distance jumped. The inclusion of these angles to predict distance jumped masked the true importance of successful predictors. The junior group

travelled less in the air than did the senior group. However, the significant predictors for distance jumped were the knee angle, the CM pathway, and the ski to trunk angle. These predictors suggested that shorter flight distances could be attained with the values associated with the junior group. However, long flight distances usually won the competition and it was the goal of every jumper to fly as far as possible. Consequently, if improvement of the angles to those exhibited by the senior group occurred, different predictors for distance jumped for the junior group could emerge. This statement implies that the junior skier must improve certain body and ski angles to effectively increase distance jumped. Once the junior jumper improves upon his body and ski positioning, longer distances will result. The predictors for distance jumped will either remain the same and be meaningful predictors or be all together different.

It appears that the multiple regression coefficient should be negative in the junior group's case, since factors for shorter flight distances, compared to the senior group, are being predicted. However, one of the limitations of multiple regression is that the correlation coefficient (r) is only reported between 0 and 1. With this in mind, the regression equation is predicting factors which contributed to the junior group's shorter flight distances.

The important predictors for the senior group were angular velocities about the hip and knee. There was a slight difference between the senior group and junior group

with regards to angular velocity. However there were fewer senior jumpers. For this reason, angular velocities could be significant predictors for distance jumped, and in fact were significant contributors for the senior group.

The combination of both groups at take-off demonstrated the importance of vertical velocity and the angle of attack. Komi et al (1974) cited a positive relationship between negative vertical velocity and distance jumped (r=.39) and stressed the importance of vertical lift. Campbell (1979) suggested the importance of the take-off angle. The current study established the importance of vertical velocity which would agree with Komi's results. As well, the angle of attack, which was comprised of the take-off angle and the ski to the horizontal, tended to agree with Campbell's results. The combination of both factors was a successful predictor for distance jumped according to the results of the present study.

At .11 seconds after take-off, the junior group indicated the ski to the horizontal angle as being a significant contributor. Again the ski to the horizontal angle between the groups was quite different with the junior group possessing a lower ski to horizontal angle which created more surface area to air resistance. The significance of this factor for the junior group again suggested a contribution towards shorter flight distances, and the junior group jumped significantly shorter.

The importance of vertical velocity and the CM pathway contributed significantly to distance jumped for the senior group. These factors stressed the importance of vertical lift and the subsequent flight path because of improved lift.

When both groups were combined at .11 seconds after take-off numerous factors contributed to distance jumped. The factors, which included linear and vertical velocity, the CM pathway, angle of attack, and angular velocity of the hip, strengthened the fact that vertical lift and the angle of the flight path were important components to determine flight distance.

At .22 and .33 seconds after take-off, similar predictors for the junior (ski to horizontal angle and angular velocity of the ankle) and senior groups (CM pathway and ski to leg angle) were encountered. Again it appeared that the predictors involved for the junior group were useful for predicting shorter flight distances because of a greater surface area exposed to the drag forces. However, the two factors could be important predictors for distance jumped if the values obtained by the juniors facilitated longer jumps. The senior group's predictors stressed the importance of the cross sectional area to air resistance and the vertical lift at take-off.

The predictors for both groups at .22 seconds after take-off (CM pathway, angle of attack, ski to trunk angle) indicated the importance of vertical lift at take-off and

the subsequent path of the centre of mass, as well as establishing proper ski and body positioning in the air. Tani and Iuchi (1971) arrived at optimal angles of ski and body positioning throughout flight on a 70 metre hill. Although comparison between the optimal angles suggested by Tani and Iuchi and those angles found in this study were not possible because of the different hill size profiles, the results encountered in this study stressed the importance of proper ski and body positioning when jumping for distance.

The predictors for distance jumped at .33 seconds after take-off included the CM pathway, the ankle angle, the ski to trunk angle, and linear velocity. The importance of proper ski and body angles was again evidenced at .33 seconds after take-off. The other important consideration was that the actions of body and skis at take-off influenced the outcome of the flight.

CHAPTER V

Summary and Conclusions

Summary

The purpose of this study was to perform a comparative analysis between two groups of ski jumpers and to ascertain the kinematic factors which influence the take-off and early flight phases of ski jumping. The film data was analyzed from a point 3 metres from the take-off to a point 7 metres after take-off.

The two groups of ski jumpers were comprised of skiers competing on the Little Thunder 25 metre ski jumping facility in Thunder Bay, Ontario on January 2, 1982. A total of 34 trials representing 15 competitors was selected for analysis. Two 16mm pin registered Photo Sonics 1PL cameras were used for the acquisition of cinematographic data. Subsequent film analysis was conducted for every second frame of the performance of each subject. A Lafayette pin registered film analyzer, Bendix digitizing board, and a Hewlett Packard 9825B micro computer were utilized for analysis. The data was input into a computer program to determine the centre of mass and its motion. In addition, the following parameters were computed: 1. the relative angular displacement and velocities about the hip, knee, and ankle; 2. the absolute angles of the trunk, thigh, and leg; 3. the angle of the CM pathway (measured to the right

horizontal); 4. the angle of the ski to the horizontal; 5. the angle of the ski to the trunk; and, 6. the angle of attack. A partitioning of the entire movement into four discrete phases was conducted prior to statistical analysis of the data.

Results

A comparative analysis of the kinematic variables emphasized the following significant differences among the senior and junior ski jumpers:

1. At take-off, the senior jumpers demonstrated a higher linear and vertical velocity of the centre of mass.
2. The knee and thigh angle were found to be larger at all positions for the senior group.
3. The trunk angle was found to be smaller at all positions except take-off for the senior group.
4. The leg angle at take-off was larger for the seniors, but at .33 seconds after take-off, the leg angle was found to be smaller.
5. The CM pathway was observed to be higher at each position for the senior group except .11 seconds after take-off.
6. At take-off, the ski to the horizontal angle was found to be higher for the senior group.
7. At all positions, it was found that the ski to trunk angle was smaller and the centre of mass to ankle distance was greater for the senior group.

The following kinematic factors of the take-off and early flight phases were found to be significant ($p<.01$) predictors for distance jumped:

1. At take-off, the junior group demonstrated the importance of the knee angle, the CM pathway, and the ski to trunk angle ($r=.75$). The senior group indicated that angular velocity of the hip and knee were important predictors ($r=.88$). When the groups were combined, the successful predictors included vertical velocity and the angle of attack ($r=.77$).
2. At .11 seconds after take-off the junior group acquired an 'r' value of .58 for the angle of the ski to the horizontal. The senior group demonstrated the importance of vertical velocity and the CM pathway with an 'r' value of .94. Both groups exhibited the successful predictors as being vertical velocity, linear velocity, CM pathway, angle of attack, and angular velocity of the hip ($r=.89$).
3. At .22 and .33 seconds after take-off, the ski to the horizontal angle and angular velocity of the ankle were important predictors for the junior group ($r=.8$ & .82 respectively). The senior group demonstrated that the CM pathway and the ski to the leg angle were important predictors ($r=.97$ & .94 respectively). When both groups were combined, the significant predictors, at .22 seconds after take-off, included the CM pathway, the angle of attack, and the ski to the trunk angle ($r=.83$).

4. At .33 seconds after take-off, both groups combined showed the importance of the CM pathway, the ankle angle, the ski to trunk angle, and linear velocity (r=.92).

Conclusions

Within the limitations of this study, the analysis of results indicated the following conclusions:

1. Significant differences were noted upon comparing two different levels of ski jumping. The performances of the junior group were significantly different from the performances of the senior group. Significant differences were observed in body position and rate of movement. Kinematic factors which significantly differed between groups included: knee angle, trunk, thigh, and leg angle, the CM pathway, the ski to the horizontal angle, the ski to trunk angle and, the horizontal distance of the centre of mass to the ankle.
2. Many different kinematic factors in each phase of this anlaysis were significant predictors for distance jumped. The importance of vertical velocity and the angle of attack at take-off is stressed. As well, the importance of the CM pathway, the angle of attack, and the ski to trunk angle early in the flight phase, contributed to distance travelled. Therefore, it can be stated that ski jumpers should optimize vertical

velocity to ensure vertical lift which will create a shallow CM pathway during flight. Also, the actions of the body and skis of the jumper at take-off influence performance in flight.

Implications

This study can be used as a guideline for the ski jumping coach to instruct his young jumpers. The differences between the young jumper and the older and more experienced jumper have been outlined and discussed. This study indicated that differences existed in a number of areas and new training methods and techniques should be considered to improve the ability of the young jumper. This study is by no means a training method to follow by the letter, however some suggestions for improvement are listed in appendix C.

Recommendations

To increase the understanding of the take-off and early flight phases, the following recommendations are suggested:

1. Replication of this study using a larger sample size to determine if there are further differences between the young and the established skiers. A larger hill size could also be utilized to determine if there are differences between groups on the larger hills.
2. Similar studies should determine the range of motion and muscular capabilities at each joint of the leg for elite and non-elite jumpers.

REFERENCES

Baumann, W. The Biomechanical Study of Ski Jumping. Scientific Study of Skiing in Japan, 1-35, 1978.

Campbell, K.R. A Kinematic Analysis of the Take-off Phase in Ski Jumping, Unpublished Masters Thesis, University of Illinois, Urbana, Illinois, 1979.

Campbell, K.R. Biomechanical Analysis of Take-off Technique in Ski Jumping. Journal of U.S. Ski Coaches Association. 3:3, 35-41, 1980.

Diffrient, N., Tilley, A.R., and Bardagjy, J.C. Humanscale 1/2/3. Massachusetts Institute of Technology, M.I.T. Press, Cambridge, Massachusetts, 1979.

Ferguson, G.A. Statistical Analysis in Psychology and Education (5th ed.). Montreal, McGraw-Hill Book Company, 1981.

Gaskill, S. An Analysis of Inrun Speed vs. Jump Length and Increasing Inrun Speeds. Journal of U.S. Ski Coaches Association. 4:1, 17-21, 1980.

Hay, J.G. Human Performance and Sport: New Perspectives for Research in Biomechanics. Paper presented at the 1st Canadian Congress for the Multi-Disciplinary Study of Sport and Physical Activity, Montreal, Canada, October 1973.

Kerlinger, F.N. and Pedhazur, E.J. Multiple Regression in Behavioural Research. Holt, Rinehart and Winston, Inc., New York, 1973.

Komi, P.U., Nelson, R.C., and Pulli, M. Biomechanics of Ski Jumping Studies of Sport. P.E. and Health No. 5, Jyvaskyla University, Finland, 1974.

Krylov, I.A. and Remizov, L.P. Problem of the optimum Ski Jump. Journal of Applied Mathematics and Mechanics. 38:4, 765-767, 1974.

Litell, R. Holmenkollen Ski Festival. Scanorama,The Magazine of SAS, 7:6, 31, 1978.

Marchiori, G.E., Bedingfield, E.W., and Hoshizaki, T.B. Stepwize Regression and Comparative Analysis of Two Groups of Ski Jumpers. Unpublished paper, 1982.

Miller, D.I. and Nelson, R.C. Biomechanics of Sport. Philadelphia, Lea & Febiger, 1973.

Nasimovich, V.K. The technique of flight and landing of the strongest Ski Jumpers. Teoriia I. Praktika Fizicheskoi Kultury, 1, 67-70, 1973.

Straumann, R. Ski Jumping and its Mechanics. Ski, Schweizer Jahrbuch, 34-64, 1927.

Tani, I. and Iuchi, M. Flight-Mechanical Investigation of Ski Jumping. In: Scientific Study of Skiing in Japan. 34-52, 1971.

Tveit, P., and Pedersen, P.O. Forces in the Take-off in Ski Jumping. Paper presentee at the VIIth International Congress of Biomechanics, Warsaw, Sept, 1979.

Walton, J.S. Close-Range Cine-Photogrammetry: A Sensualized Technique for Quantifying Gross Human Motion. Doctoral Thesis (Penn State), 1981.

Watanabe, L., Kasaya, A., Kawahara, Y., and Konishi, T. Kinematic Studies on Ski Jump. International Congress of Winter Sports Medicine, 98-105, 1972.

Watanabe, L. and Kawahara, Y. Measurements of Approach Time and Flight in Ski Jumping and Discussion on the Take-off. R.J.P.E., 15:1, 42, 1970.

Winter, D.A. Biomechanics of Human Movement. John Wiley & Sons, Inc. 1979, pp. 25-39.

Zubarev, U.M. and Grozin, E. A. The Kinematic Parameters of Push-off on Ski Jumps. Teoriia I. Praktika Fizicheskoi Kultury. 38:2, 16-19, 1975.

APPENDIX A

Computer Programs

```
0: % "PROGRAM FOR ANALYZING SKI JUMPING"
1: dsp "DATA DIGITIZING + STORAGE";wait 1500
2: dsp "PROGRAM FOR 40 FRAMES";wait 1500
3: ent "# OF FRAMES",N
4: ent "TIME INTERVAL BETWEEN FRAMES",T
5: dim A[N,30],B[N,30],D[6],Z$[N+1,20]
6: ent "FRAME # FOR TAKE-OFF",r10
7: ent "FRAME # FOR RE-REFERENCE",r11
8: ent "DIGITIZE REFERENCE ? [1=YES]",r0
9: if r0=1;gsb "cfac"
10: if r0#1;ent "CONVERSION FACTOR =",O
11: if r12=2;gto +3
12: ent "NAME OF SUBJECT",Z$[1]
13: 1→A
14: dsp "RESET ORIGIN";wait 2000;beep
15: ent "DESCRIPTION OF FRAME",Z$[A+1]
16: dsp "DIGITIZE TOP OF HEAD";red 4,X,Y;X→B[A,1];Y→B[A,15];beep
17: dsp "DIGITIZE NECK";red 4,X,Y;X→A[A,1]→A[A,2]
18: Y→A[A,15]→A[A,16];beep
19: dsp "DIGITIZE RIGHT SHOULDER";red 4,X,Y;X→A[A,3];Y→A[A,17];beep
20: dsp "DIGITIZE LEFT SHOULDER";red 4,X,Y;X→A[A,6];Y→A[A,20];beep
21: dsp "DIGITIZE RIGHT ELBOW";red 4,X,Y;X→A[A,4]→B[A,3]
22: Y→A[A,18]→B[A,17];beep
23: dsp "DIGITIZE LEFT ELBOW";red 4,X,Y;X→A[A,7]→B[A,6]
24: Y→A[A,21]→B[A,20];beep
25: dsp "DIGITIZE RIGHT WRIST";red 4,X,Y;X→A[A,5]→B[A,4]
26: Y→A[A,19]→B[A,18];beep
27: dsp "DIGITIZE LEFT WRIST";red 4,X,Y;X→A[A,8]→B[A,7]
28: Y→A[A,22]→B[A,21];beep
29: dsp "DIGITIZE RIGHT HAND";red 4,X,Y;X→B[A,5];Y→B[A,19];beep
30: dsp "DIGITIZE LEFT HAND";red 4,X,Y;X→B[A,8];Y→B[A,22];beep
31: dsp "DIGITIZE RIGHT HIP";red 4,X,Y;X→B[A,2]→A[A,9]
32: Y→B[A,16]→A[A,23];beep
33: dsp "DIGITIZE LEFT HIP";red 4,X,Y;X→A[A,12];Y→A[A,26];beep
34: dsp "DIGITIZE RIGHT KNEE";red 4,X,Y;X→A[A,10]→B[A,9]
35: Y→A[A,24]→B[A,23];beep
36: dsp "DIGITIZE LEFT KNEE";red 4,X,Y;X→A[A,13]→B[A,12]
37: Y→A[A,27]→B[A,26];beep
38: dsp "DIGITIZE RIGHT ANKLE";red 4,X,Y;X→B[A,10];Y→B[A,24];beep
39: dsp "DIGITIZE LEFT ANKLE";red 4,X,Y;X→B[A,13];Y→B[A,27];beep
40: dsp "DIGITIZE RIGHT HEEL";red 4,X,Y;X→A[A,11];Y→A[A,25];beep
41: dsp "DIGITIZE LEFT HEEL";red 4,X,Y;X→A[A,14];Y→A[A,28];beep
42: dsp "DIGITIZE RIGHT TOE";red 4,X,Y;X→B[A,11];Y→B[A,25];beep
43: dsp "DIGITIZE LEFT TOE";red 4,X,Y;X→B[A,14];Y→B[A,28];beep
44: dsp "DIGITIZE FRONT SKI";red 4,X,Y;X→A[A,29];Y→B[A,29];beep
45: dsp "DIGITIZE BACK SKI";red 4,X,Y;X→A[A,30];Y→B[A,30];beep
46: if A=r10;dsp "DIGITIZE TAKE-OFF";red 4,X,Y;beep;X→D[2];Y→D[3]
47: ent "ERROR ?? [1=YES]",r0
48: if r0=1;dsp "DIGITIZE FRAME AGAIN";wait 3000;gto 16
49: if A<N;A+1→A;ent "TIME INTERVAL",D[A-1];if A<r11 or A>r11;gto 15
50: if A=r11;2→r12;gto 8
51: gsb "store"
52: dsp "STORAGE DONE";end
```

```
53: "cfac":
54: dsp "DIGITIZE POINT 1";red 4,X,Y;beep
55: dsp "DIGITIZE POINT 2";red 4,K,L;beep
56: ent "REAL SIZE OF REFERENCE [cm]",O
57: O/√((K-X)^2+(L-Y)^2)→O;fxd 2;prt "C.F.=",O
58: if A#r11;O→D[4]
59: if A=r11;O→D[5]
60: ret
61: "store":
62: N→D[1];T→D[6]
63: N*30*2*8+(N+6)*8→Q;fxd 0;prt "BYTES 1st",Q
64: (N+1)*22+6+1→W;fxd 0;prt "BYTES 2nd",W;spc
65: ent "MARK FILE THEN PRESS CONTINUE",O
66: ent "FILE#",Q;ent "TRACK #",r0
67: trk r0;rcf Q,A[*],B[*],D[*]
68: rcf Q+1,Z$
69: trk 0
70: wtb 7,10,10,13
71: fmt ,9x,18"*",x,c20,x,17"*",/,/
72: wrt 7,"FILE CONTENTS RECORD"
73: fmt 1,9x,c10,c8,f2.0,c12,f2.0,2x,c
74: wrt 7.1,"DATA SPEC:","IN FILE",Q,"IN TRACK",r0,Z$[1]
75: wtb 7,10,13
76: fmt 2,9x,c7,f3.0,c46
77: for J=1 to D[N]
78: wrt 7.2,"FRAME #",J,Z$[J+1]
79: next J
80: fmt 3,/,/,9x,c;fmt 4,9x,c5,f8.3,c;wrt 7.3,"COMMENTS :"
81: wrt 7.4,"D[1]=",D[1],"=# OF FRAMES"
82: wrt 7.4,"D[2]=",D[2],"=X COORDINATE FOR TAKE-OFF POINT"
83: wrt 7.4,"D[3]=",D[3],"=Y COORDINATE FOR TAKE-OFF POINT"
84: wrt 7.4,"D[4]=",D[4],"=CONVERSION FACTOR - 1ST FILM"
85: wrt 7.4,"D[5]=",D[5],"=CONVERSION FACTOR - 2ND FILM"
86: wrt 7.4,"D[6]=",D[6],"=TIME BETWEEN FRAMES"
87: wtb 7,12;ret
```

```
0: % "PROGRAM FOR ANALYZING SKI JUMPING"
1: dsp "S K I C O S M O K I N E P L O T";wait 3000
2: ent "ENTER # OF FRAMES (max 60)",N
3: dim A[N,30],B[N,30],D[6],E[N,30],L[N],M[N]
4: dim S[5],T[N-1],X[3,N],C$[7,65],K$[7,20],N$[14,10],Q$[5]
5: ent "FILE #",F;ent "TRACK #",T
6: ent "ENTER MASS OF SUBJECT",r40;ent "SKI MASS",r41
7: ent "FRAME # WHERE REREFERENCE",R;ent "TAKE-OFF FRAME",r30
8: ent "SAMPLING FREQUENCY",r32;ent "CUT-OFF FREQUENCY",r33
9: trk T;ldf F,A[*],B[*],D[*]
10: gsb "LABEL"
11: beep;ent "COMMENTS",C$[7]
12: gsb "COOR"
13: gsb "SMOOTH"
14: gsb "KINEM"
15: gsb "OUT-PUT"
16: gsb "PLOT"
17: wtb 7,27,69;dsp "  O  F  F";end
18:
19: "KINEM":dsp "  K I N E M A T I C S"
20: .5→L[1]→L[2];.436→L[3]→L[6];.43→L[4]→L[7];.28→L[5]→L[8]
21: .433→L[9]→L[10]→L[12]→L[13];.45→L[11]→L[14]
22: r40→W;r41→S;1→B;.45→H;W+S+B+H→Q
23: (.096W+H)/Q→M[1];(.0145W+B/2)/Q→M[11]→M[14]
24: .458W/Q→M[2];S/Q→M[15];.033W/Q→M[3]→M[6];.019W/Q→M[4]→M[7]
25: .0065W/Q→M[5]→M[8];.105W/Q→M[9]→M[12];.045W/Q→M[10]→M[13]
26: for Q=1 to N;for A=1 to 14
27: M[A](A[Q,A]-(A[Q,A]-B[Q,A])L[A])→E[Q,A]
28: M[A](A[Q,A+14]-(A[Q,A+14]-B[Q,A+14])L[A])→E[Q,A+15]
29: next A
30: M[15]B[Q,11]→E[Q,15];M[15]B[Q,25]→E[Q,30]
31: next Q
32: for I=1 to N;0→C→D
33: for A=1 to 15;E[I,A]+C→C;E[I,A+15]+D→D;next A
34: C→L[I];D→M[I]
35: next I
36: for Q=2 to N
37: L[Q]-L[Q-1]→E[Q,1];M[Q]-M[Q-1]→E[Q,2]
38: √(E[Q,1]^2+E[Q,2]^2)→E[Q,3]
39: if Q=2 or Q=N;cll 'DER'(L[Q],L[Q-1],D[6],E[Q,4]);gto +1
40: if Q=2 or Q=N;cll 'DER'(M[Q],M[Q-1],D[6],E[Q,5]);gto +3
41: cll 'DER'(L[Q+1],L[Q-1],2D[6],E[Q,4])
42: cll 'DER'(M[Q+1],M[Q-1],2D[6],E[Q,5])
43: √(E[Q,4]^2+E[Q,5]^2)→E[Q,6]
44: next Q
45: for F=1 to N
46: cll 'DOT'(A[F,2],A[F,16],A[F,9],A[F,23],A[F,10],A[F,24],E[F,7])
47: cll 'DOT'(A[F,9],A[F,23],A[F,10],A[F,24],B[F,10],B[F,24],E[F,8])
48: cll 'DOT'(A[F,10],A[F,24],B[F,10],B[F,24],B[F,11],B[F,25],E[F,9])
49: 1→A;cll 'TRIG'(A[F,2],A[F,16],A[F,9],A[F,23],A,E[F,10])
50: 0→A;cll 'TRIG'(A[F,9],A[F,23],A[F,10],A[F,24],A,E[F,11])
51: 1→A;cll 'TRIG'(A[F,10],A[F,24],B[F,10],B[F,24],A,E[F,12])
52: next F
```

```
53: % "ANGLE OF C.of M. PATHWAY"
54: for I=2 to N;atn((M[I]-M[I-1])/(L[I]-L[I-1]))→E[I,13];next I
55: for A=1 to N
56: % "ANGLE OF SKI WITH HOR."
57: atn((B[A,29]-B[A,30])/(A[A,29]-A[A,30]))→E[A,14]
58: % "ANGLE OF TRUNK WITH SKI"
59: E[A,10]-E[A,14]→E[A,15]
60: % "ANGLE OF LEG WITH SKI"
61: E[A,12]-E[A,14]→E[A,16]
62: next A
63: % "ANGLE OF ATTACK"
64: for I=2 to N;E[I,14]-E[I,13]→E[I,17];next I
65: % "HOR. DISTANCE C.M. TO ANKLE"
66: for I=1 to N;L[I]-B[I,10]→E[I,18];next I
67: % "ANGULAR VELOCITY OF HIP, KNEE, ANKLE"
68: for A=2 to N;for E=7 to 9;E+12→D
69: if A=2 or A=N;cll ´DER´(E[A,E],E[A-1,E],D[6],E[A,D]);gto +2
70: cll ´DER´(E[A+1,E],E[A-1,E],2D[6],E[A,D])
71: next E;next A
72: ret
73:
74: "PLOT":dsp "   P L O T "
75: for S=1 to 6
76: if S>1;gto +5
77: 0→T[1]
78: for I=2 to N-1;T[I-1]+D[6]→T[I];next I
79: for A=1 to N;E[A,18]→X[1,A];next A
80: gto +24
81: if S>2;gto +5
82: for A=1 to N;for B=1 to 3
83: E[A,6+B]→X[B,A]
84: next B;next A
85: gto +19
86: if S>3;gto +5
87: for A=1 to N;for B=1 to 3
88: E[A,13+B]→X[B,A]
89: next B;next A
90: gto +14
91: if S>4;gto +5
92: for A=2 to N;for B=1 to 3
93: E[A,3+B]→X[B,A-1]
94: next B;next A
95: gto +9
96: if S>5;gto +5
97: for A=2 to N;for B=1 to 3
98: E[A,18+B]→X[B,A-1]
99: next B;next A
100: gto +4
101: for A=2 to N
102: E[A,13]→X[1,A-1];E[A,17]→X[2,A-1]
103: next A
104:
```

```
105: % "X axis scale → r5;  Y axis scale → r6"
106: 0→r1;T[N-1]→r2;1.05r2→r2
107: min(X[*])→r3;max(X[*])→r4;1.2r4→r4
108: 708.66/abs(r2-r1)→r5;377.95/abs(r4-r3)→r6
109: if r3<0;450+abs(r3r6)→O
110: if r3>=0;450→O
111: wtb 7,27,79,int(200/64),int(200),int(O/64),int(O)
112: % Yaxis
113: wtb 7,27,46,124,0,3,0
114: r6r4→r7;r6r3→r8;r5r2→r9;r5r1→r22
115: wtb 7,27,65,0,0,int(r7/64),int(r7)
116: if S=2 or S=3 or S=6;wtb 7,27,10,8,8,8;wrt 7,N$[2];gto +2
117: wtb 7,27,10,8,8,8;wrt 7,N$[S]
118: wtb 7,27,65,0,0,int(r7/64),int(r7)
119: wtb 7,27,97,0,0,int(r8/64),int(r8)
120: % Xaxis
121: wtb 7,27,46,95,0,5,9;if r3>=0;gto +3
122: wtb 7,27,65,int(r22/64),int(r22),0,0
123: wtb 7,27,97,int(r9/64),int(r9),0,0
124: wtb 7,27,65,int(r22/64),int(r22),int(r8/64),int(r8)
125: wtb 7,27,97,int(r9/64),int(r9),int(r8/64),int(r8);wrt 7,N$[14]
126: for W=1 to 3
127: if S>3;X[W,1]r6→r20;T[2]r5→r21;gto +2
128: X[W,1]r6→r20;T[1]r5→r21
129: if W=1;wtb 7,27,46,46,int(4/64),4,9;gto +3
130: if W=2;wtb 7,27,46,39,int(4/64),4,9;gto +2
131: wtb 7,27,46,42,int(4/64),4,9
132: wtb 7,27,65,int(r21/64),int(r21),int(r20/64),int(r20)
133: for J=2 to N-3
134: if S>3;X[W,J]r6→r20;T[J+1]r5→r21;gto +2
135: X[W,J]r6→r20;T[J]r5→r21
136: wtb 7,27,97,int(r21/64),int(r21),int(r20/64),int(r20)
137: next J
138: if S=1;gto +3
139: if S=6 and W=2;gto +2
140: next W
141: r3→r10;r4→r11;(r4-r3)/8→r12
142: fmt 1,f7.2,c
143: r6r10→L
144: wtb 7,27,65,int(-90/64),int(-90),int(L/64),int(L)
145: wrt 7.1,r10,"-";r10+r12→r10
146: if r10<r11;jmp -3
147: r1→r10;r2→r11;(r2-r1)/10→r12
148: 0→A;r8→O;fmt 2,f5.2
149: wtb 7,27,65,int(A/64),int(A),int(O/64),int(O);wrt 7,"|"
150: wtb 7,27,65,int((A-24)/64),int(A-24),int((O-16)/64),int(O-16)
151: wrt 7.2,r10;r10+r12→r10;r10r5→A
152: if r10<r11;jmp -3
153: wtb 7,27,65,int(50/64),int(50),int((O-50)/64),int(O-50)
154: fmt 1,c;wrt 7.1,C$[S];fmt 2,21x,c;wtb 7,10;wrt 7.2,C$[7]
155: wtb 7,27,46,124,0,3,0
156: wtb 7,27,65,int(T[r30]r5/64),int(T[r30]r5),int(r7/64),int(r7)
157: wtb 7,27,10,8,8,8;wrt 7,N$[13]
158: wtb 7,27,65,int(T[r30]r5/64),int(T[r30]r5),int(r7/64),int(r7)
159: wtb 7,27,97,int(T[r30]r5/64),int(T[r30]r5),int(r8/64),int(r8)
160: for A=1 to 3;for B=1 to N
161: 0→X[A,B]
162: next B;next A
163: wtb 7,12;next S
164: ret
165:
```

```
166: "OUT-PUT":dsp "  O U T    P U T"
167: fmt 1,8x,c6,c14,2c17;fmt 2,14x,c14,2c17
168: fmt 3,9x,f3.0,2x,2f16.5,f18.5;fmt 4,8x,c5,x,2c19,2x,c
169: fmt 5,22x,c5,12x,c5,14x,c;fmt 6,24x,c5,11x,c5,13x,c
170: fmt 7,8x,c5,c19,c18,2x,c
171: fmt 8,8x,c5,2c19,2x,c
172: wrt 7,C$[7];wtb 7,10,10,13
173: wrt 7.1,N$[3],N$[7],N$[8],N$[9];wrt 7.2,N$[6],N$[6],N$[6];wtb 7,10
174: for A=1 to N
175: wrt 7.3,A,E[A,7],E[A,8],E[A,9]
176: next A;wtb 7,12
177: wrt 7.1,N$[3],N$[10],N$[11],N$[12];wrt 7.2,N$[6],N$[6],N$[6];wtb 7,10
178: for A=1 to N
179: wrt 7.3,A,E[A,10],E[A,11],E[A,12]
180: next A;wtb 7,12
181: wrt 7.4,N$[3],K$[1],K$[2],K$[3];wrt 7.6,N$[6],N$[6],N$[6];wtb 7,10
182: for A=1 to N
183: wrt 7.3,A,E[A,13],E[A,14],E[A,15]
184: next A;wtb 7,12
185: wrt 7.7,N$[3],K$[4],K$[5],K$[6];wtb 7,10
186: for A=1 to N
187: wrt 7.3,A,E[A,16],E[A,17],E[A,18]
188: next A;wtb 7,12
189: wrt 7.8,N$[3],K$[7],K$[7],K$[7];wrt 7.5,N$[7],N$[8],N$[9];wtb 7,10
190: for A=1 to N
191: wrt 7.3,A,E[A,19],E[A,20],E[A,21]
192: next A
193: wtb 7,10,10,13;wrt 7,E[10,5];wtb 7,10,13;wrt 7,E[10,6];wtb 7,12;ret
194:
195: "COOR":dsp "  C O O R D I N A T E S"
196: 2.3393→r0
197: for A=1 to R-1;for B=1 to 30
198: cll 'CONV'(A[A,B],D[4],A[A,B])
199: cll 'CONV'(B[A,B],D[4],B[A,B])
200: next B;next A
201: for I=R to N;for J=1 to 14
202: cll 'XTR'(A[I,J],A[I,J+14],r2)
203: cll 'YTR'(A[I,J],A[I,J+14],r3)
204: cll 'YTR'(B[I,J],B[I,J+14],r5)
205: cll 'XTR'(B[I,J],B[I,J+14],r4)
206: r2→A[I,J];r3→A[I,J+14]
207: r4→B[I,J];r5→B[I,J+14]
208: next J
209: cll 'XTR'(A[I,29],B[I,29],r2)
210: cll 'YTR'(A[I,29],B[I,29],r3)
211: cll 'XTR'(A[I,30],B[I,30],r4)
212: cll 'YTR'(A[I,30],B[I,30],r5)
213: r2→A[I,29];r3→B[I,29]
214: r4→A[I,30];r5→B[I,30]
215: next I
216: for A=R to N;for B=1 to 30
217: cll 'CONV'(A[A,B],D[5],A[A,B])
218: cll 'CONV'(B[A,B],D[5],B[A,B])
219: next B
220: for T=1 to 14
221: A[A,T]-.11→A[A,T];B[A,T]-.11→B[A,T]
222: next T
223: A[A,29]-.11→A[A,29];A[A,30]-.11→A[A,30]
224: next A
225: ret
226:
```

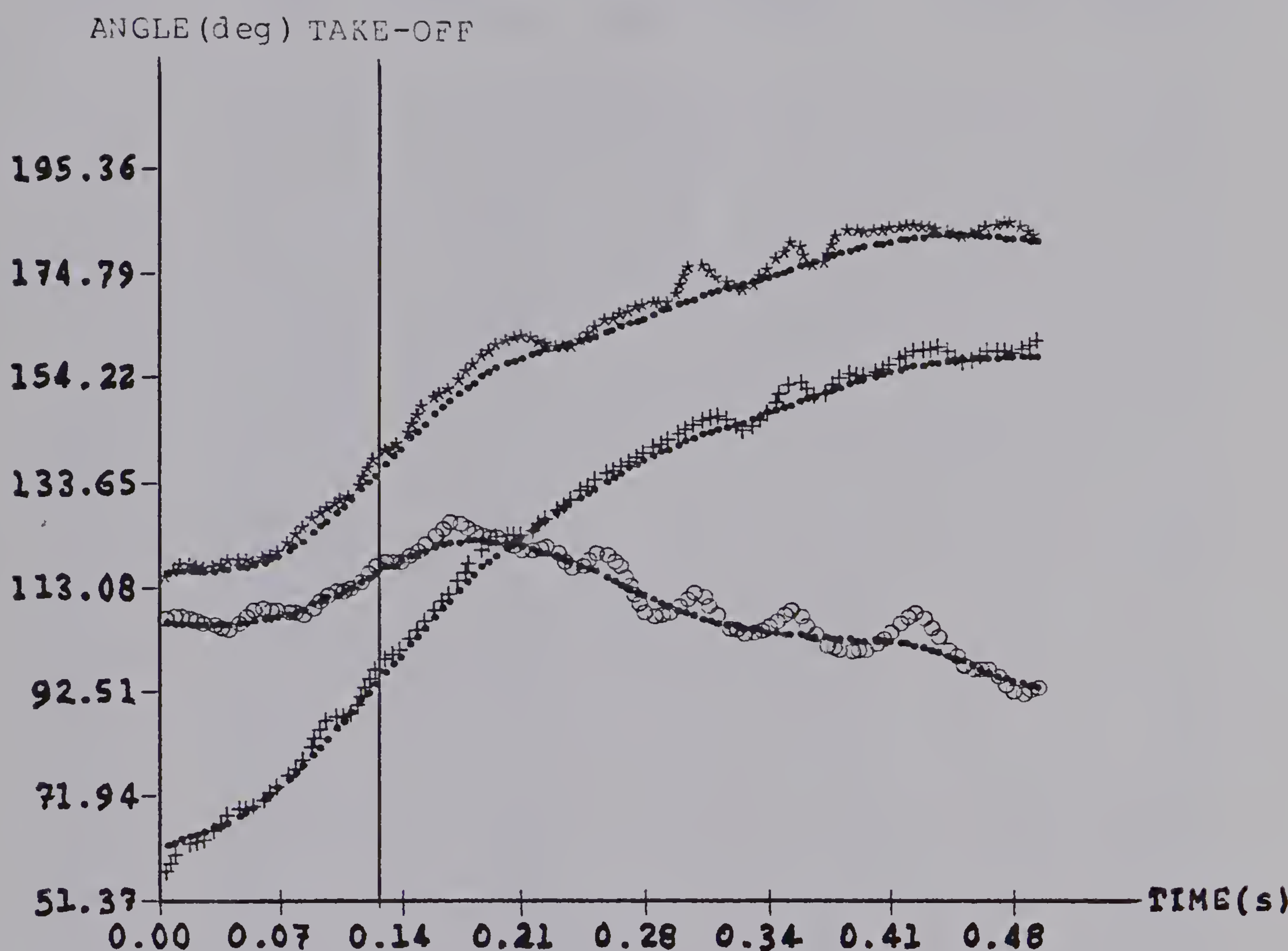
```
"SMOOTH":r32→S;r33→C
2πC→C;tan(C/2S)→C;360C/2π/(√2-1)^.25→C
C^2/(1+√2C+C^2)→S[1]→S[3];2S[1]→S[2]
(1-√2C+C^2)/(1+√2C+C^2)→S[4]
2(C^2-1)/(1+√2C+C^2)→S[5]
dsp "   A[...]  F I R S T - P A S S"
for B=1 to 30
for I=1 to 2;A[I,B]→E[I,B];next I
for A=3 to N
cll 'SSS'(A[A-2,B],A[A-1,B],A[A,B],E[A-2,B],E[A-1,B],E[A,B])
next A;next B
for I=1 to 30;for J=N to 1 by -1
E[J,I]→A[N-J+1,I]
next J;next I
if flg1;cfg 1;gto +2
dsp "   A[...]  B A C K - P A S S";sfg 1;gto -9
dsp "   B[...]  F I R S T - P A S S"
for B=1 to 30
for I=1 to 2;B[I,B]→E[I,B];next I
for A=3 to N
cll 'SSS'(B[A-2,B],B[A-1,B],B[A,B],E[A-2,B],E[A-1,B],E[A,B])
next A;next B
for I=1 to 30;for J=N to 1 by -1
E[J,I]→B[N-J+1,I]
next J;next I
if flg1;cfg 1;ret
dsp "  B[...]  B A C K - P A S S ";sfg 1;gto -9

"SSS":S[1]p1+S[2]p2+S[3]p3-S[4]p4-S[5]p5→p6;ret
"CONV":p1p2/100→p3;ret
"XTR":p1cos(r0)-p2sin(r0)→p3;ret
"YTR":p1sin(r0)+p2cos(r0)→p3;ret
"DER":(p1-p2)/p3→p4;ret
"DOT":p1-p3→p8;p2-p4→p9;p5-p3→p10;p6-p4→p11
acs((p8p10+p9p11)/(√(p8^2+p9^2)*√(p10^2+p11^2)))→p7;ret
"TRIG":acs((p1-p3)/√((p1-p3)^2+(p2-p4)^2))→p6;if p5=0;180-p6→p6
ret
"LABEL":
"HORIZONTAL DISTANCE OF C.M. TO ANKLE"→C$[1]
"ANGLES OF HIP(.), KNEE(,), ANKLE(*)"→C$[2]
"ANGLES OF SKI-HORIZ(.), SKI-TRUNK(,), SKI-LEG(*)"→C$[3]
"C.M. VELOCITIES HORIZONTAL(.), VERTICAL(,), LINEAR(*)"→C$[4]
"ANGULAR VELOCITIES OF HIP(.), KNEE(,), ANKLE(*)"→C$[5]
"ANGLES OF C.M. PATHWAY(.), OF ATTACK(,)"→C$[6]
"DIST(m.)"→N$[1];"ANGLE(d)"→N$[2]
"VEL(m/s)"→N$[4];"VEL(d/s)"→N$[5];" TIME(s)"→N$[14]
"FRAME"→N$[3];"ANGLE"→N$[6];"HIP"→N$[7];"KNEE"→N$[8];"ANKLE"→N$[9]
"TRUNK"→N$[10];"THIGH"→N$[11];"LEG"→N$[12];"TAKEOFF"→N$[13]
"C.M. PATHWAY"→K$[1];"SKI TO HORIZONTAL"→K$[2];"SKI TO TRUNK"→K$[3]
"LEG-SKI ANGLE"→K$[4];"ANGLE OF ATTACK"→K$[5]
"HOR/DIST CM-ANKLE"→K$[6];"ANGULAR VELOCITY"→K$[7]
ret
```

APPENDIX B

Figure Presentation of

Raw vs Smooth Data



Raw vs Smooth Data
for One Subject

RAW vs SMOOTH DATA FOR A SELECTED SUBJECT

FR.#	HIP ANGLE RAW	HIP ANGLE SMOOTH	KNEE ANGLE RAW	KNEE ANGLE SMOOTH	ANKLE ANGLE RAW	ANKLE ANGLE SMOOTH
1	51.372	59.404	108.412	113.034	103.534	103.203
2	58.122	61.179	112.738	113.433	103.626	103.020
3	59.579	62.722	111.283	113.461	102.729	102.961
4	65.145	64.800	113.721	113.816	101.165	103.179
5	65.848	67.718	113.062	114.926	105.628	103.776
6	70.154	71.539	115.689	117.005	105.037	104.805
7	75.821	76.145	120.720	120.059	104.423	106.343
8	83.485	81.291	124.167	123.943	108.582	108.440
9	84.228	86.744	126.462	128.463	109.430	110.998
10	94.194	92.333	134.357	133.393	114.940	113.743
11	97.320	97.915	136.909	138.466	114.939	116.321
12	103.583	103.362	144.800	143.375	118.722	118.397
13	108.458	108.534	147.931	147.805	123.147	119.694
14	114.958	113.256	152.666	151.485	119.935	120.085
15	119.686	117.405	156.712	154.260	119.701	119.657
16	119.503	121.036	157.989	156.183	116.565	118.613
17	123.167	124.354	155.468	157.575	117.700	117.141
18	126.783	127.524	155.672	158.881	112.615	115.346
19	131.031	130.572	160.168	160.408	116.930	113.238
20	133.179	133.441	162.296	162.194	113.467	110.859
21	135.895	136.050	164.307	164.112	103.295	108.469
22	138.631	138.326	164.348	165.988	104.765	106.400
23	141.686	140.236	173.253	167.651	109.303	104.742
24	143.011	141.868	168.573	169.065	102.626	103.424
25	139.661	143.438	166.749	170.412	99.947	102.431
26	143.869	145.118	171.214	171.895	101.940	101.722
27	150.770	146.881	177.025	173.514	105.713	101.136
28	146.187	148.609	170.468	175.158	98.626	100.585
29	151.171	150.246	179.356	176.702	97.046	100.179
30	150.801	151.768	178.363	177.992	97.400	99.931
31	153.410	153.110	179.256	178.923	101.219	99.729
32	155.527	154.183	179.674	179.498	104.961	98.951
33	156.333	154.938	178.839	179.820	93.937	97.424
34	153.168	155.444	177.042	179.932	93.320	95.409
35	155.989	155.818	179.408	179.611	93.377	93.415
36	155.165	156.099	179.939	179.221	88.103	91.867
37	158.362	156.249	177.101	178.884	90.253	90.952
38	154.796	156.242	176.788	178.690	89.589	90.553
39	153.041	156.064	179.170	178.576	93.747	90.331
40	156.373	155.559	176.446	178.362	84.289	89.877

APPENDIX C

Checklist for Jumpers

CHECKLIST

Take-off

1. The skier should maintain a small leg angle throughout the in-run. Greater blocks on the heels of the skis and/or increased flexibility at the ankle of the athlete would achieve a small leg angle.
2. The skier should maintain the proper in-run position longer. The longer the skier is in the in-run position before the take-off, the longer the surface area is reduced, resulting in increased linear velocity.
3. The skier should improve timing of the extension at the hip, knee, and ankle. This timing should proceed in the manner of extending first at the hip, then the knee, and finally at the ankle, and should coincide at take-off. This timing can be achieved through dryland jumping techniques.
4. The skier should increase the hip and knee angle by extending forward and not upward.
5. The skier should attempt to increase vertical velocity by extending at the leg joints at the appropriate time and in the appropriate direction. This increased vertical velocity would result in a shallower angle of the CM in the air.

Flight

1. The movements of the body and skis at take-off greatly influence the airborne phase.
2. The trunk angle should be as close to horizontal as possible. The skier should attempt to extend forward, not upward.
3. The knee and thigh angle will increase if the trunk angle is kept at a minimum.
4. To decrease air resistance, decrease the trunk angle and increase the ski to the horizontal angle.
5. The CM path will depend on the vertical force at take-off. If the skier increases the vertical force, increased lift will result and a shallow CM path will also result.
6. The skier should attempt to reduce the surface area exposed to air resistance by leaning forward at the hips and increasing the ski to the horizontal angle.